NEW

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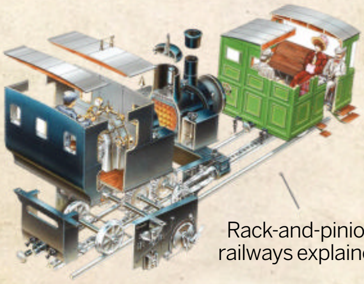
Rack-and-pinion railways explained

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HOW IT WORKS

BOOK OF

INCREDIBLE HISTORY

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD WE LIVED IN

MH-60 Black Hawk

Record-breaking royals

Currency and trade

The last days of the dinosaurs

Accidental discoveries

History's deadliest warriors

How was the guillotine invented?

Get to know the Aztec warriors

Digital Edition

FUTURE
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INDUSTRY & INVENTIONS · INFLUENTIAL FIGURES · PREHISTORIC

Welcome to

HOW IT WORKS
BOOK OF

INCREDIBLE HISTORY

What were the first cities of the ancient world like? What really happened to the dinosaurs? How did the secretive work of spies evolve over the centuries? Why was the Terracotta Army found buried beside the tomb of a Chinese Emperor? The How It Works Book of Incredible History is dedicated to answering all these questions and many more. In this new edition we journey through the ages and celebrate history's most intriguing customs, traditions and inventions – ones which changed the world forever. Not only will you traverse time periods, you will tour time zones via our eclectic range of subjects: the ancient world, iconic buildings and landmarks, weapons and warfare, masterful inventions, influential visionaries and prehistoric predators. Packed with fascinating facts and figures accompanied by gorgeous photographs, diagrams and illustrations, turn the page and be inspired as history is brought to life before your eyes!

HOW IT WORKS BOOK OF INCREDIBLE HISTORY

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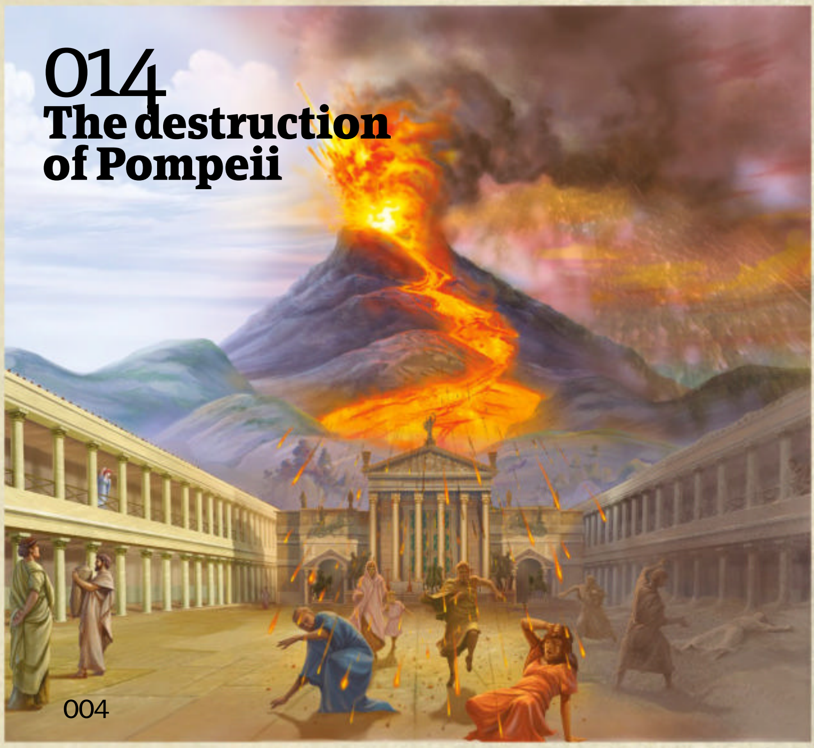

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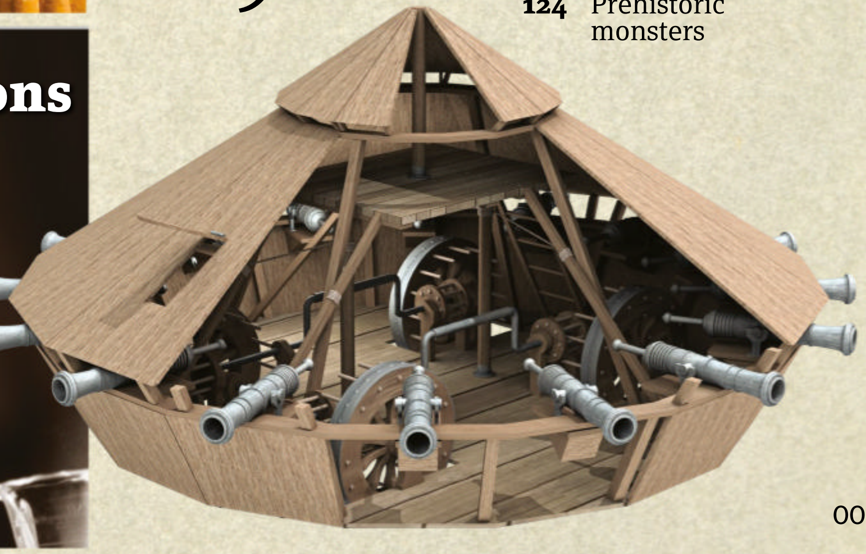

Leonardo's machines 090

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ANCIENT HISTORY

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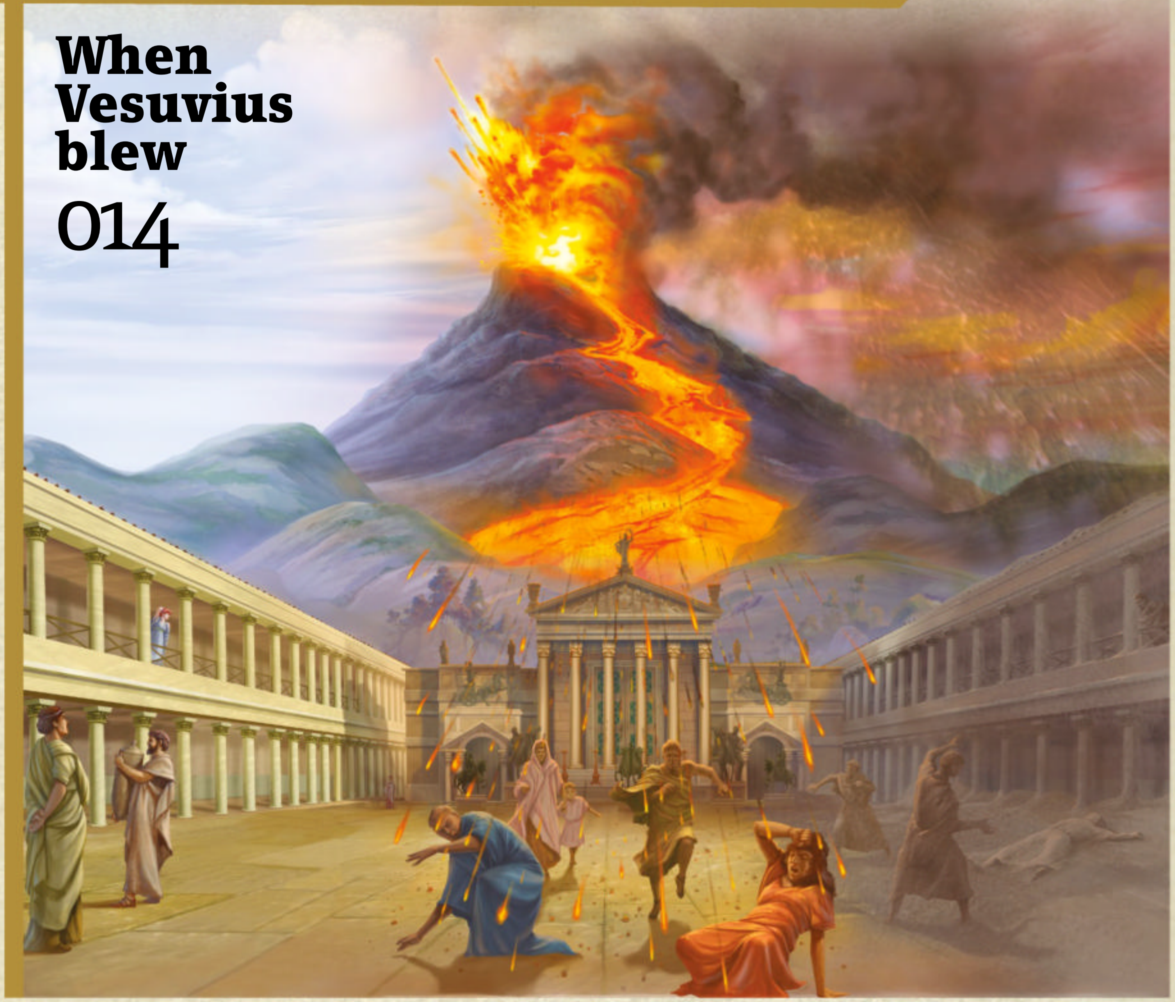

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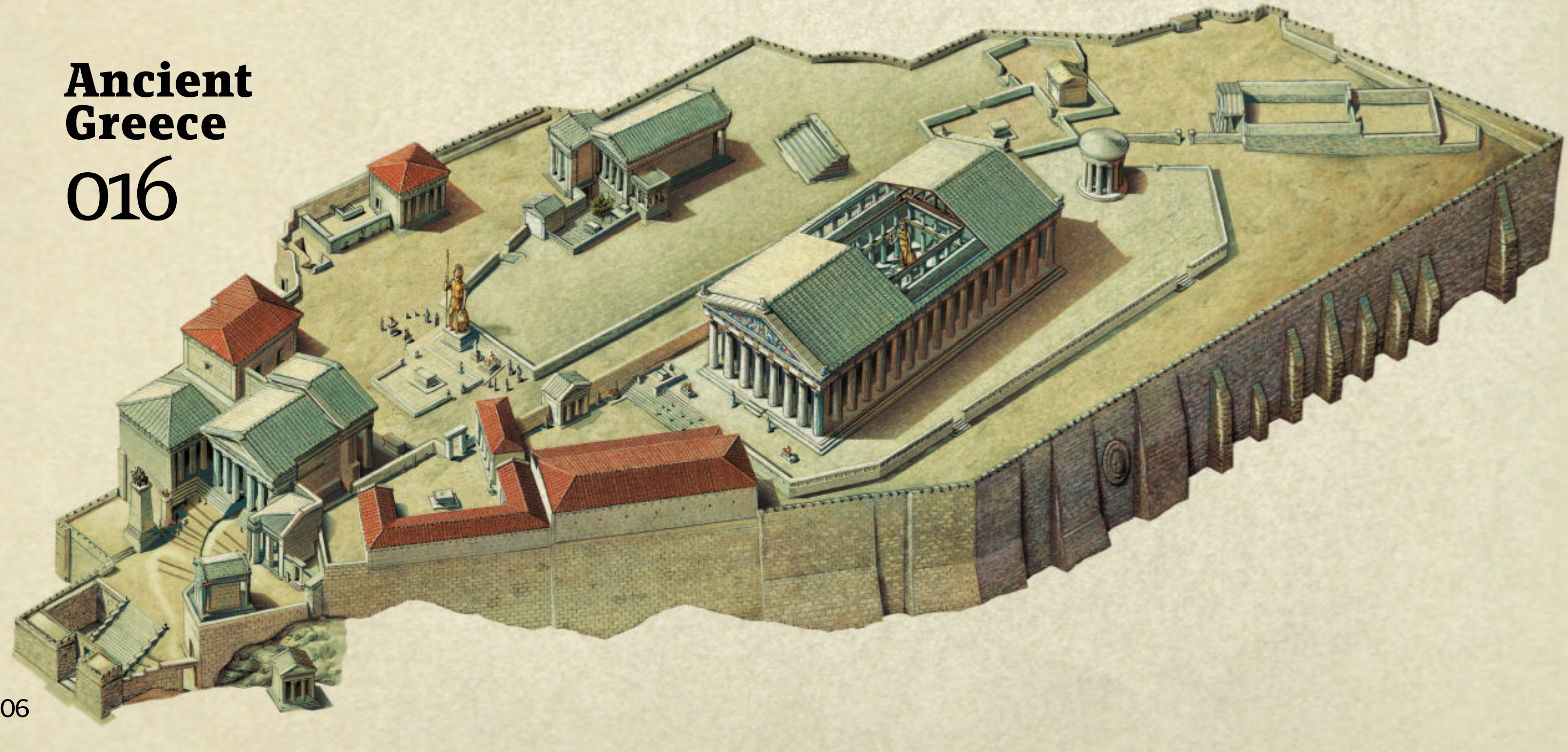

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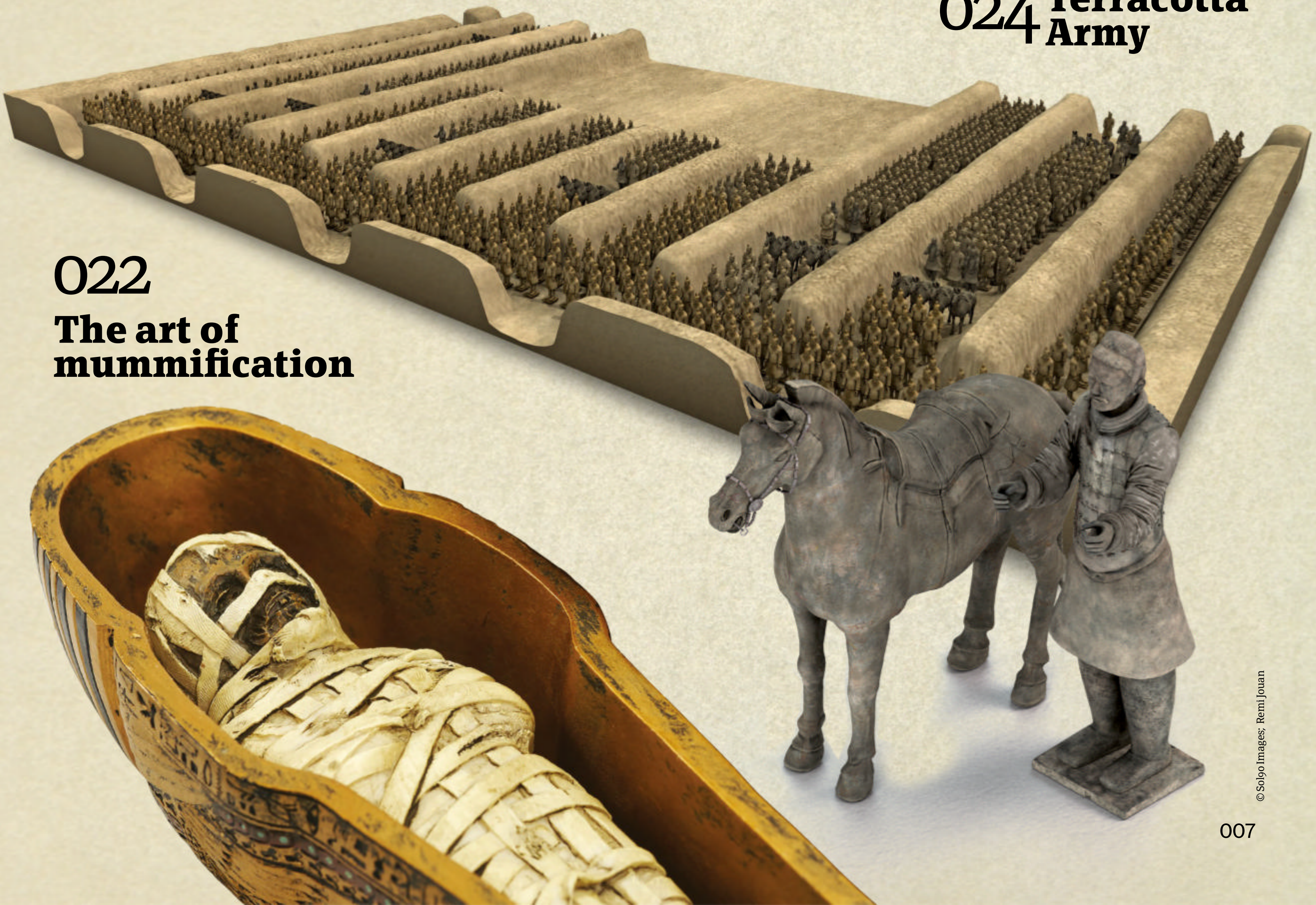

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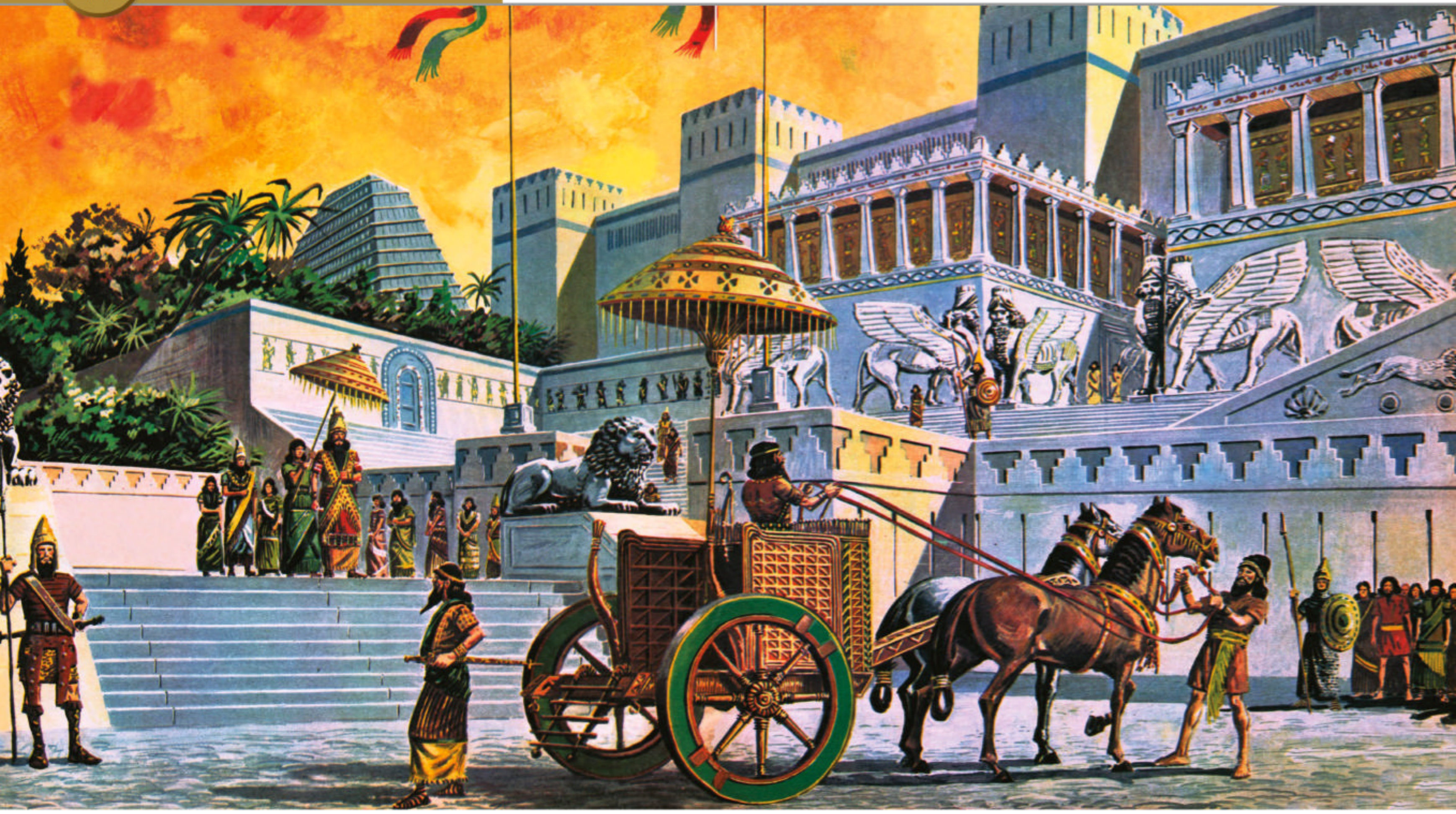
© Solo Images; Remi Jouan



Mesopotamia: The creators of civilisation

Discover how society as we know it began in a small region of modern day Iraq

The ancient region of Mesopotamia has fascinated, enthralled and perplexed historians and scientists for thousands of years. Unlike the ancient empire of Greece, or even Egypt, it was not a united nation. Made up of a vast collection of varied cultures, city-states and beliefs, Mesopotamia was a land of multiple empires and diverse civilisations. It is perhaps thanks to this variety that Mesopotamia gave birth to what we recognise as civilisation today.

The list of Mesopotamian innovations is endless, and it is difficult to contemplate how modern life would be without them. Mesopotamia was home to the first ever cities, writing took form there and the oldest wheeled vehicles in the world were found in Mesopotamian ruins. Animals were domesticated, humanity came on leaps and bounds in agriculture, innovative new tools were crafted, weapons were swung and wine was drunk. Mesopotamians were the first people to study the night sky, track the Moon and declare that there were 60 minutes in an hour, and 60 seconds in a minute.

Mesopotamia was driven by religion, and it was one of the few things that united the lands that made up the region. From this religion sprang customs, moral codes and social hierarchy. In many ways the Mesopotamians were ahead of their time, as women were regarded as individuals in their own right, free to own land, file for divorce and run businesses.

The Mesopotamian version of the Creation story declared that the world was formed when the gods achieved victory over the forces of chaos, and the same could be said in the creation of Mesopotamia itself. With its kings, taxes and trade, it was a triumph of man's ability to conquer and thrive, and it set the blueprints for countless cities, countries and empires that followed.

SUMER

5400 BCE
The city of Eridu is founded; it is considered the first true city in the world.

3600 BCE
Writing first emerges in the form of cuneiform. Reeds are used to make marks in wet clay.

3500 BCE
Religion is first referenced in writing, in the form of Sumerian cuneiform tablets.

2334-2218 BCE
During this period Sumer is conquered by the powerful emperor Sargon the Great and comes under the rule of the Akkadian Empire.

DID YOU KNOW? *Although most of Mesopotamia shared a common religion, each city had its own patron god*

What it was like to live there

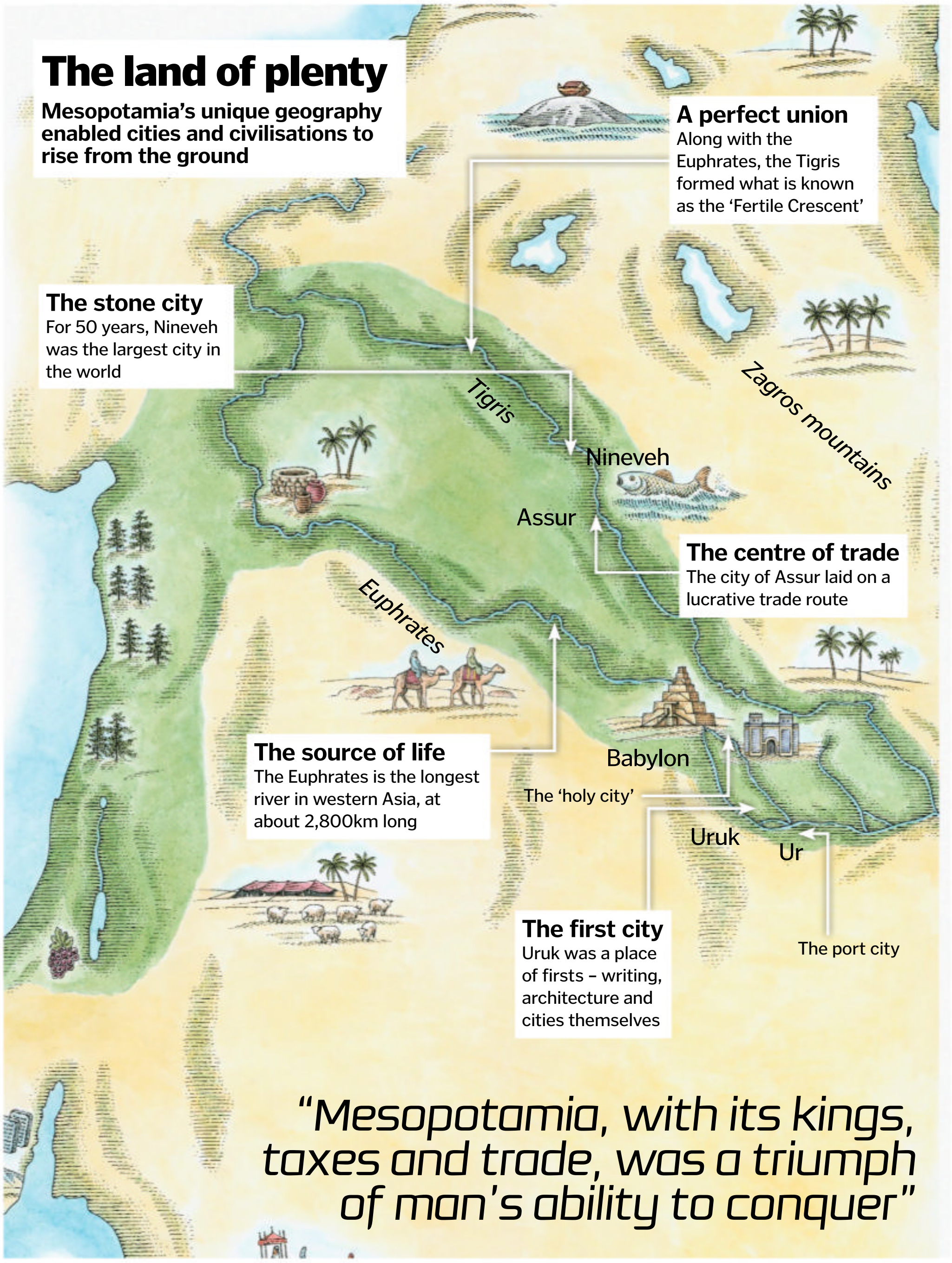
The word 'Mesopotamia' means 'between the rivers', which literally describes the location of the region. Mesopotamia lay between the Tigris and Euphrates rivers, which today flow through modern day Turkey, Iraq and Syria. All the regions of Mesopotamia experienced different geography, which led to variation in how people there lived. Lying between two rivers had some risks as the land was subject to frequent and unpredictable flooding, which could play havoc with farmers' crops. These floods went hand in hand with periods of drought. However, the swelling rivers helped to create very fertile soil that supported plants even with minimal rainfall, and allowed boats to be used as a quick means of transportation. Mesopotamians became skilled farmers and traded their crops for resources they were lacking, such as building materials like wood, metal and stone. The people took advantage of the ready supply of water by building canals to support the trade network and were able to flourish in spite of the lack of natural resources in some areas.

ON THE MAP

Mesopotamia

The land of plenty

Mesopotamia's unique geography enabled cities and civilisations to rise from the ground



A perfect union
Along with the Euphrates, the Tigris formed what is known as the 'Fertile Crescent'

The stone city
For 50 years, Nineveh was the largest city in the world

The centre of trade
The city of Assur laid on a lucrative trade route

The source of life
The Euphrates is the longest river in western Asia, at about 2,800km long

The 'holy city'

The first city
Uruk was a place of firsts – writing, architecture and cities themselves

The port city

> *"Mesopotamia, with its kings, taxes and trade, was a triumph of man's ability to conquer"*

The rise of civilisation

Three of the major cultures that arose in Mesopotamia and influenced society

SUMERIANS

The southernmost region of Mesopotamia, Sumer comprised modern day southern Iraq and Kuwait. Sumer was first inhabited in approximately 4500 BCE, or possibly even earlier. It is in Sumer that the first cities in the world were established, starting with Uruk. Sumerians believed that their cities represented god's triumph over chaos.

BABYLONIANS

Meaning 'gate of the gods', Babylonia lay in central southern Mesopotamia (modern day Iraq). Its earliest days are a mystery lost to rising sea levels, but from 1792 BCE the famous king Hammurabi came into power and the city of Babylon – built upon the Euphrates river – became the beating heart of Mesopotamia.

ASSYRIANS

Located in the Near East, the ancient kingdom of Assyria comprised regions of Iraq, Syria and Turkey. It drove technological, scientific and warfare developments in Mesopotamia. The Assyrian empire gradually expanded to unite most of the Middle East, increasing their power and wealth to become a formidable force.

© Thinkstock; Look&Learn; CGTextures

2150-1400 BCE
The Epic of Gilgamesh is written during this time. This famous poetic work stands as one of the oldest pieces of western literature in existence.

2100 BCE
The Sumerian King List is created, establishing the idea of kingship as a divine institution.

1800 BCE
All the cities of Sumer, and of Mesopotamia, are united by Hammurabi, who makes Babylon his capital.

1750 BCE
A combination of invasion, migration and the sacking of Ur brings an end to the Sumerian civilisation.

The world's first cities

With its reliable source of food, people gathered in Mesopotamia and formed the very first cities

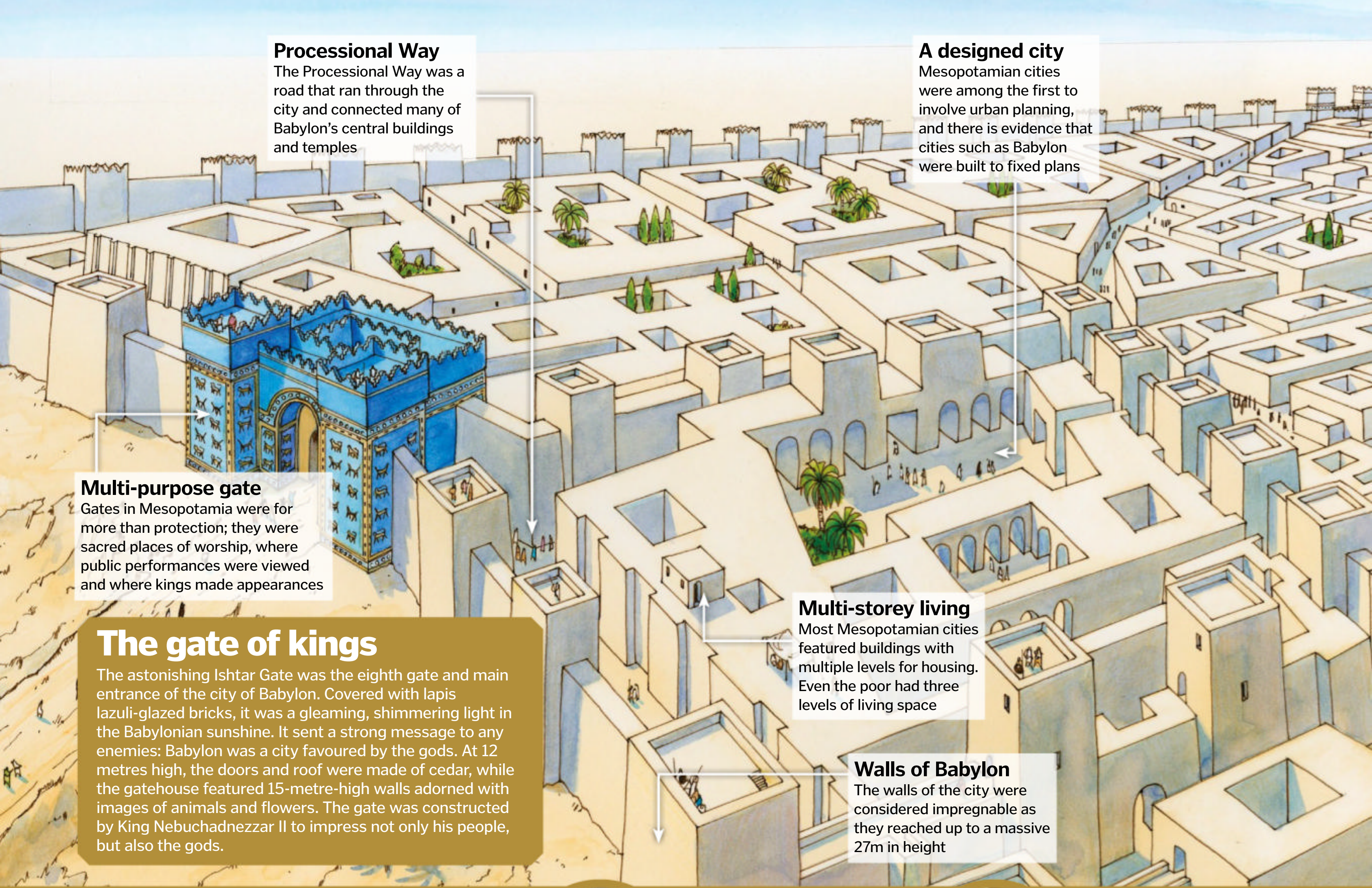
Mesopotamia was home to some of the very first cities in existence, leading many to link it to the birth of true civilisation. The origin of these cities is still unknown today, although many theories exist. One suggestion is that the development and building of temples created a place where people would gather, and thus served as points of contact between different groups of people.

Others believe that people sought sanctuary from natural disasters. As the Mesopotamians were able to develop technology to help them control the nearby rivers, such as levees, they could ensure a good crop. They had no need to be nomadic, and were able to settle in one place comfortably. It is for this reason that all the early cities were built along the two major rivers.

From the moment the Sumerians began to form these cities, it forever altered human history. People went from being ruled by nature, to attempting to control it and make it work for them. By 4500 BCE the first recorded city rose in the form of Uruk. However, the only urban structure at this point was the temple, which regulated all economic and social matters.

The central purpose of these early cities was to help regulate trade, as southern Mesopotamia was reliant on outside resources. This need encouraged the spread of urbanisation. However, communication between the cities was difficult, so each city developed into an individual city-state. This led to territorial disputes and, inevitably, war.

In order to keep their cities protected, the Mesopotamians built fortifications, and walled cities rose. Migration to these cities increased, and more buildings were erected. Cities gradually expanded and rulers were proclaimed, who then began looking outwards for trade and conquest.



Processional Way
The Processional Way was a road that ran through the city and connected many of Babylon's central buildings and temples

A designed city
Mesopotamian cities were among the first to involve urban planning, and there is evidence that cities such as Babylon were built to fixed plans

Multi-purpose gate
Gates in Mesopotamia were for more than protection; they were sacred places of worship, where public performances were viewed and where kings made appearances

Multi-storey living
Most Mesopotamian cities featured buildings with multiple levels for housing. Even the poor had three levels of living space

Walls of Babylon
The walls of the city were considered impregnable as they reached up to a massive 27m in height

The gate of kings

The astonishing Ishtar Gate was the eighth gate and main entrance of the city of Babylon. Covered with lapis lazuli-glazed bricks, it was a gleaming, shimmering light in the Babylonian sunshine. It sent a strong message to any enemies: Babylon was a city favoured by the gods. At 12 metres high, the doors and roof were made of cedar, while the gatehouse featured 15-metre-high walls adorned with images of animals and flowers. The gate was constructed by King Nebuchadnezzar II to impress not only his people, but also the gods.

BABYLONIA

1894 BCE
The first Babylonian dynasty emerges; this Amorite dynasty forms a small kingdom including the city of Babylon.

1792 BCE
Hammurabi begins his reign as ruler of Babylon. He transforms it from a tiny town to a powerful city.

1792-1750 BCE
During his reign, Hammurabi introduces some of the earliest examples of laws in the form of the Code of Hammurabi.

1755 BCE
Hammurabi conquers and unites Mesopotamia under his rule, and Babylon becomes known as a holy city.

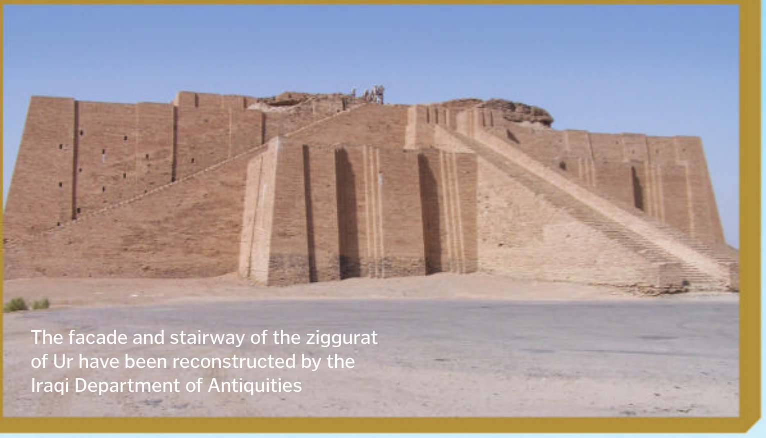
DID YOU KNOW? No trace of Babylon's famous 'hanging gardens' remains; some experts believe they were in Nineveh instead

Towering temples

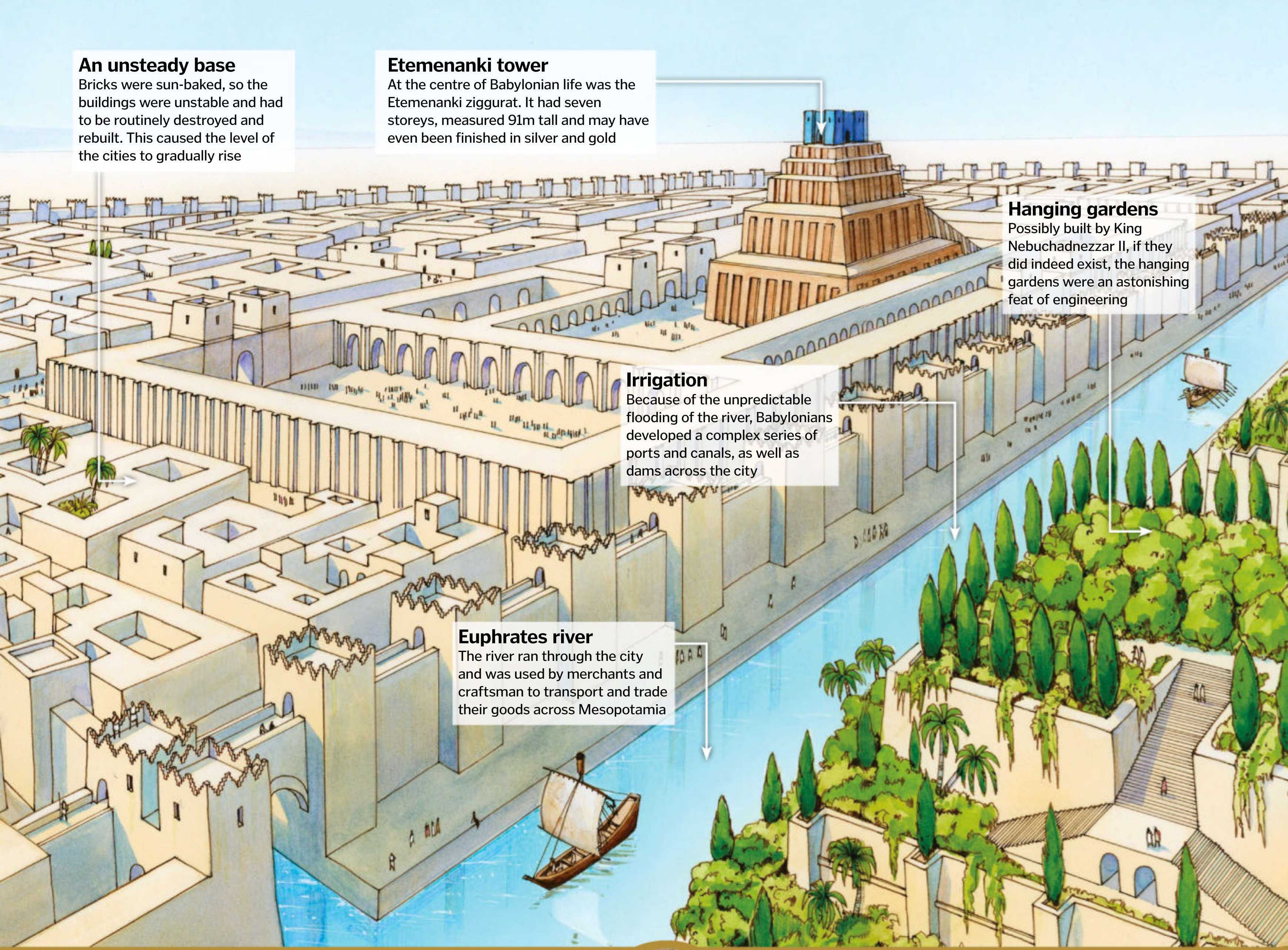
Ziggurats were temples built on high, stepped platforms. Although they originated in Sumerian cities in 2000 BCE, they gradually spread to all of Mesopotamia, including Babylonia and Assyria. The stepped towers were mainly constructed from sun-dried bricks layered between reeds. It is believed that many ziggurats featured a shrine at the top, but no examples of this remain.

Although their exact purpose cannot be verified, it is known that ziggurats were linked to religion, and each ziggurat was connected to large temple complexes. There was a belief in Mesopotamia that the gods resided in the Eastern mountains; therefore building high temples would more closely connect the people with god, linking heaven with Earth.

A practical purpose of the high platforms was to escape any rising floodwater that rushed into the lowlands. The structure of the ziggurat, which was accessible only by three stairways, also ensured that the rituals conducted within remained secret and sacred.



The facade and stairway of the ziggurat of Ur have been reconstructed by the Iraqi Department of Antiquities



An unsteady base
Bricks were sun-baked, so the buildings were unstable and had to be routinely destroyed and rebuilt. This caused the level of the cities to gradually rise

Etemenanki tower
At the centre of Babylonian life was the Etemenanki ziggurat. It had seven storeys, measured 91m tall and may have even been finished in silver and gold

Hanging gardens
Possibly built by King Nebuchadnezzar II, if they did indeed exist, the hanging gardens were an astonishing feat of engineering

Irrigation
Because of the unpredictable flooding of the river, Babylonians developed a complex series of ports and canals, as well as dams across the city

Euphrates river
The river ran through the city and was used by merchants and craftsman to transport and trade their goods across Mesopotamia

Circa 1750 BCE

Babylonian mathematicians introduce the concept of place value in numbers. Astronomers also name the planets and constellations.

1595 BCE

Babylon is sacked by the Hittite king Mursili I. This marks the beginning of the Babylonian 'dark ages'.

1595-1155 BCE

The Kassite dynasty rules over Babylonia. They rename Babylon 'Kar-Duniash' but it continues to serve as the capital of the kingdom.

1225 BCE

The Assyrian ruler Tukulti-Ninurta I destroys the armies of Babylon and sacks the city. He goes on to become king.

Seven ways Mesopotamia changed the world

The phrase 'the foundations of civilisation' is often used while talking about Mesopotamia. But what exactly does this mean? Is civilisation simply people living together, or does it involve more? Agriculture had emerged by 8000 BCE, and art was produced for thousands of years before Mesopotamia rose. However, Mesopotamia took these aspects of human culture and transformed them into civilisation as we know it today.

Brought together by a common goal – to find food – the Mesopotamians developed some of the earliest writing known to man, borne out of necessity to record accounts and crop yields. However, it later developed to represent more abstract ideas. As people were gathered together, spiritual practices were also refined, and the population began to share a common belief system. With this established, the priests, who claimed to be able to communicate with the gods, took their place at the top of the social hierarchy, and slowly a class system developed. This emphasis on religion inspired moral codes, which led to formal rules and, in turn, punishment for those who disobeyed.

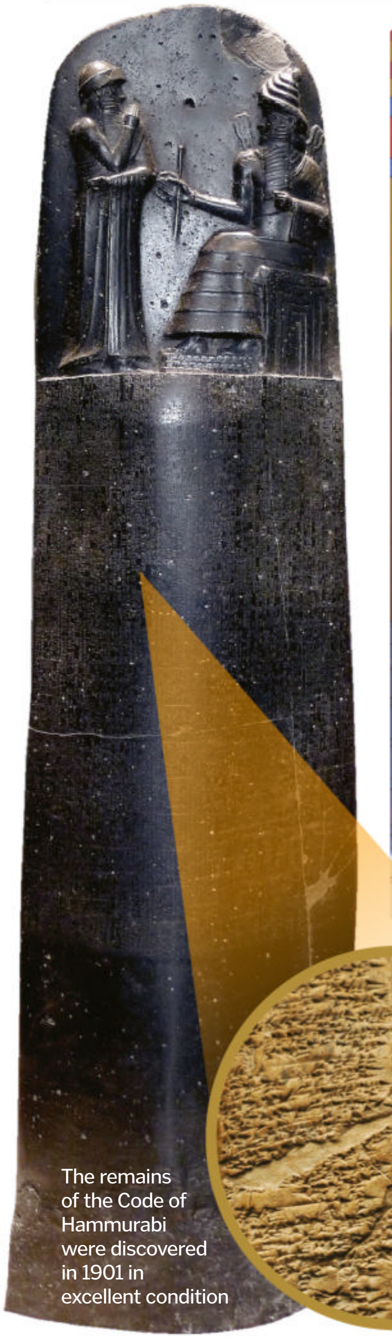
A steady food supply meant the Mesopotamians could pursue other aspects of life, such as technology and science. They made groundbreaking advancements in the areas of mathematics and medicine. However, this social structure also revealed the darker aspects of humanity, such as war, slavery and expansion, and with so many people gathered together, diseases spread rapidly.

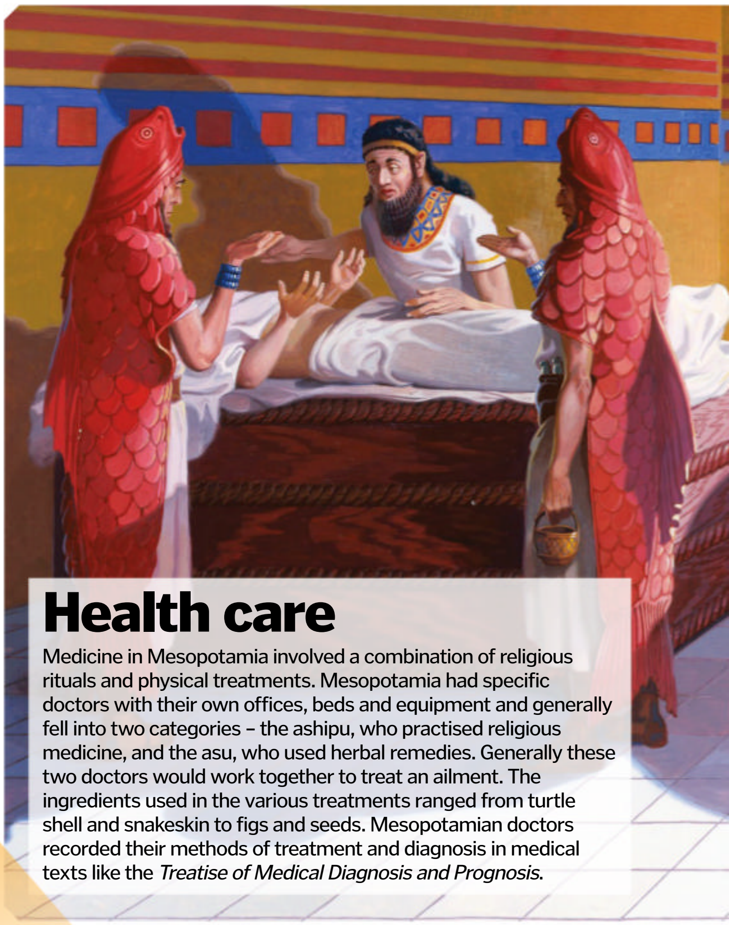
As the civilisation developed, it inevitably had an influence on other cultures. It is believed that Babylonian astronomy influenced Greece, India and even China. The early Mesopotamian codes of laws also had a profound effect on lawmaking in the Near East, and the introduction of taxes and a standing army influenced countries worldwide. In fact, historians are still exploring the huge impact that Mesopotamia had on the ancient world, and the world we live in today.

The creation of writing

Writing began in Mesopotamia towards the end of the 4th millennium BCE as a way to record crucial information about crops and taxes in pictorial form. These early tablets developed into a script, which bears close resemblance to writing today. This system of writing is commonly known as cuneiform and comprised of wedge-shaped marks in clay. Gradually the number of characters used in cuneiform decreased from 1,000 to around 400, which ensured more clarity in the script. By 2500 BCE cuneiform was advanced enough to portray emotions such as fear and hope.

The word cuneiform itself simply means 'wedge-shaped'


The remains of the Code of Hammurabi were discovered in 1901 in excellent condition



Health care

Medicine in Mesopotamia involved a combination of religious rituals and physical treatments. Mesopotamia had specific doctors with their own offices, beds and equipment and generally fell into two categories – the ashipu, who practised religious medicine, and the asu, who used herbal remedies. Generally these two doctors would work together to treat an ailment. The ingredients used in the various treatments ranged from turtle shell and snakeskin to figs and seeds. Mesopotamian doctors recorded their methods of treatment and diagnosis in medical texts like the *Treatise of Medical Diagnosis and Prognosis*.

Thou shalt obey

Law codes as we know them were first seen in Mesopotamia. One of the earliest is the Code of Hammurabi, which features 282 laws dealing with a huge variety of issues in great detail, from marriage to theft. For example, if a man rents a boat to a sailor and it is wrecked, the sailor has to give the man a new boat. Although it is the most well-known, the Code of Hammurabi was pre-dated by other law codes, such as the code of Lipit-Ishtar and those written by the Sumerian king Ur-Nammu, who described the purpose of his laws as protecting the weak from the mighty.

ASSYRIA

2600 BCE
The city of Ashur, capital of Assyria, is founded, along with other Assyrian cities.

1813–1776 BCE
Shamshi-Adad I rules Assyria. He expands the empire, secures Assyria's borders and builds up a powerful army.

1472 BCE
The kingdom of Mitanni, a powerful northern Mesopotamian state, annexes Assyria and the land loses its independence.

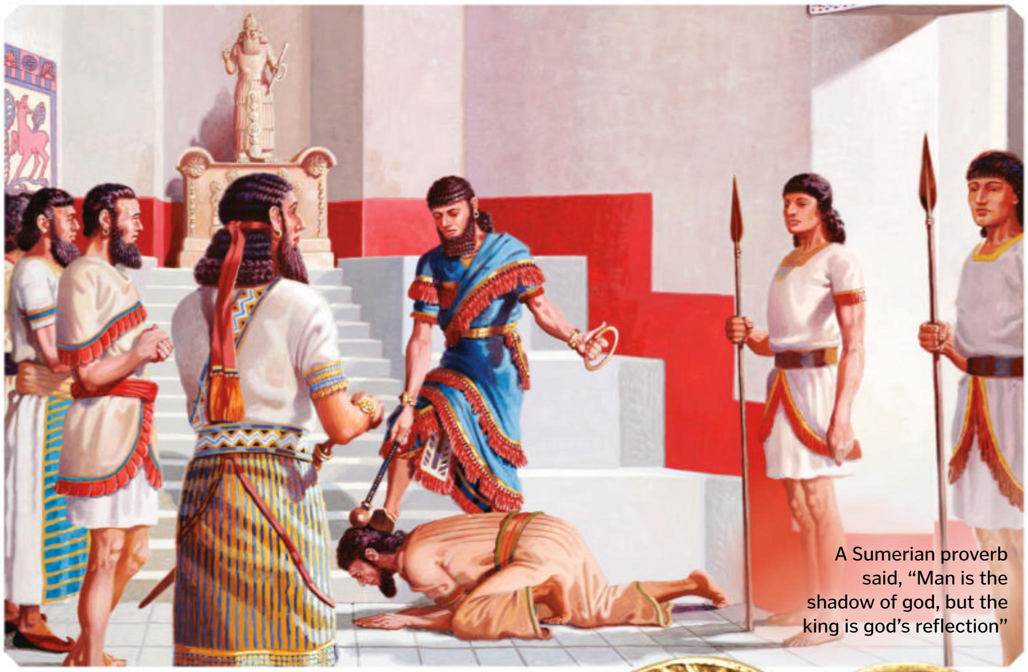
1365–1330 BCE
Ashur-uballit I defeats the Mitanni, and under his leadership, Assyria develops as a powerful and rapidly expanding empire.

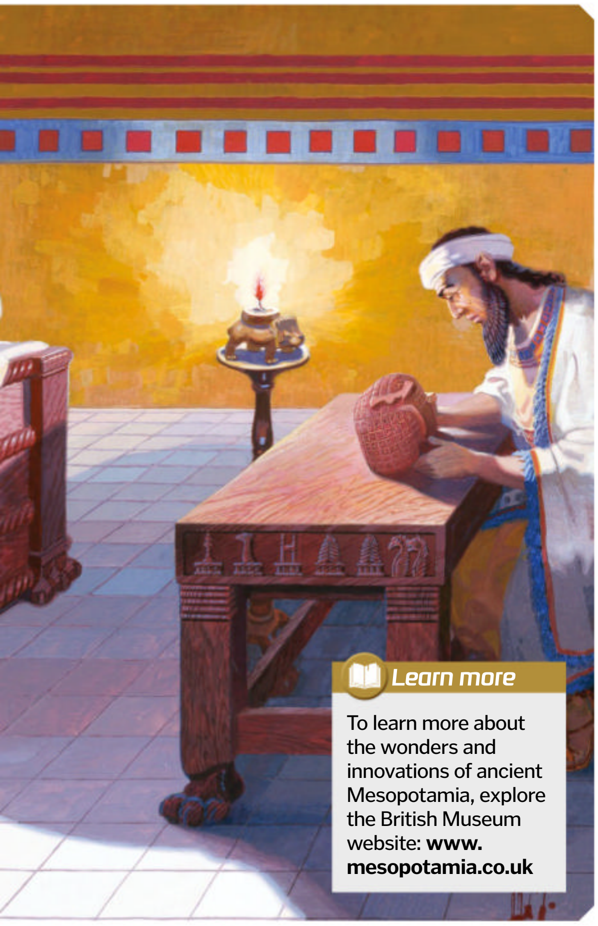
1244–1208 BCE
The warrior king, Tukulti-Ninurta I, reigns. Assyria expands to its greatest extent and defeats the ruler of Babylonia.

DID YOU KNOW? *Assyrian warfare was brutal; the words 'I destroyed, devastated and burned with fire' appeared on inscriptions*

Only the strong shall lead

Mesopotamia was made up of several city-states which each had their own leaders and government, with kings ruling over individual regions. This led to a lot of internal fighting between different kings for land and resources. The first kings were the leaders of armies, who then went on to continue to lead during peacetime. Because of the strong emphasis on religion, the kings often served as high priests and therefore were linked to the divinity of god, and claimed to be god's representatives on Earth. Some of these kings, such as Sargon, sought to unite many of the city-states under one leader and capital.


A Sumerian proverb said, "Man is the shadow of god, but the king is god's reflection"



Learn more

To learn more about the wonders and innovations of ancient Mesopotamia, explore the British Museum website: **www.mesopotamia.co.uk**

Mesopotamian money

Mesopotamians used silver rings thousands of years before the first coins were made. In around 2500 BCE a 'shekel' of silver became the currency of Mesopotamia, with one month of labour being worth one shekel, and a slave worth between ten and 20. Prior to this, clay tokens in a variety of sizes and shapes were used for trade and barter. There were at least 16 different types of these tokens that represented various things, such as rope, sheep's milk, perfume and honey.

This Carthaginian shekel from 310-290 BCE is similar to the Mesopotamian shekel

The Standard of Ur, an artefact dating from around 2600 BCE, depicts wheeled chariots being used in battle

The basis of time

The Mesopotamians were trailblazers in their concept of time. They were the first in recorded history to use a base 60 numerical system that led to our 60-second minutes and 60-minute hours. Many believe that this helped the Babylonians make such impressive advances in mathematics, as 60 has many divisors. They also used a lunar calendar, which comprised 12 lunar months, at an average of 29.5 days each. This left the Mesopotamians short by around 11 days a year, so they added seven months in each 19-year period to keep the seasons aligned.

The Royal Game of Ur, one of the oldest in the world, was played with early Mesopotamian mathematics

A wheely late invention

The wheel was actually invented at a surprisingly late point of human history, with the oldest example from Mesopotamia dating to 3500 BCE, in the Bronze Age. It is likely that the wheel was developed individually by different cultures around the same time. Evidence shows that Mesopotamians used this invention for pottery first, before adapting the design for transport with chariots. Wheels did offer advantages to transportation, but they took a great deal of time to make as smooth as possible, so sledges were still commonly used alongside the wheel.

1000 BCE

Assyria establishes the first cavalry force. As this is before the invention of saddles, the warriors ride bareback.

668-627 BCE

During his reign, King Ashurbanipal establishes a huge library, housing a collection of thousands of clay tablets.

612 BCE

Many Assyrian cities, including Ashur and Nineveh, are sacked and destroyed by a combined force of Medes, Persians and Babylonians.

© Alamy

How Vesuvius destroyed Pompeii

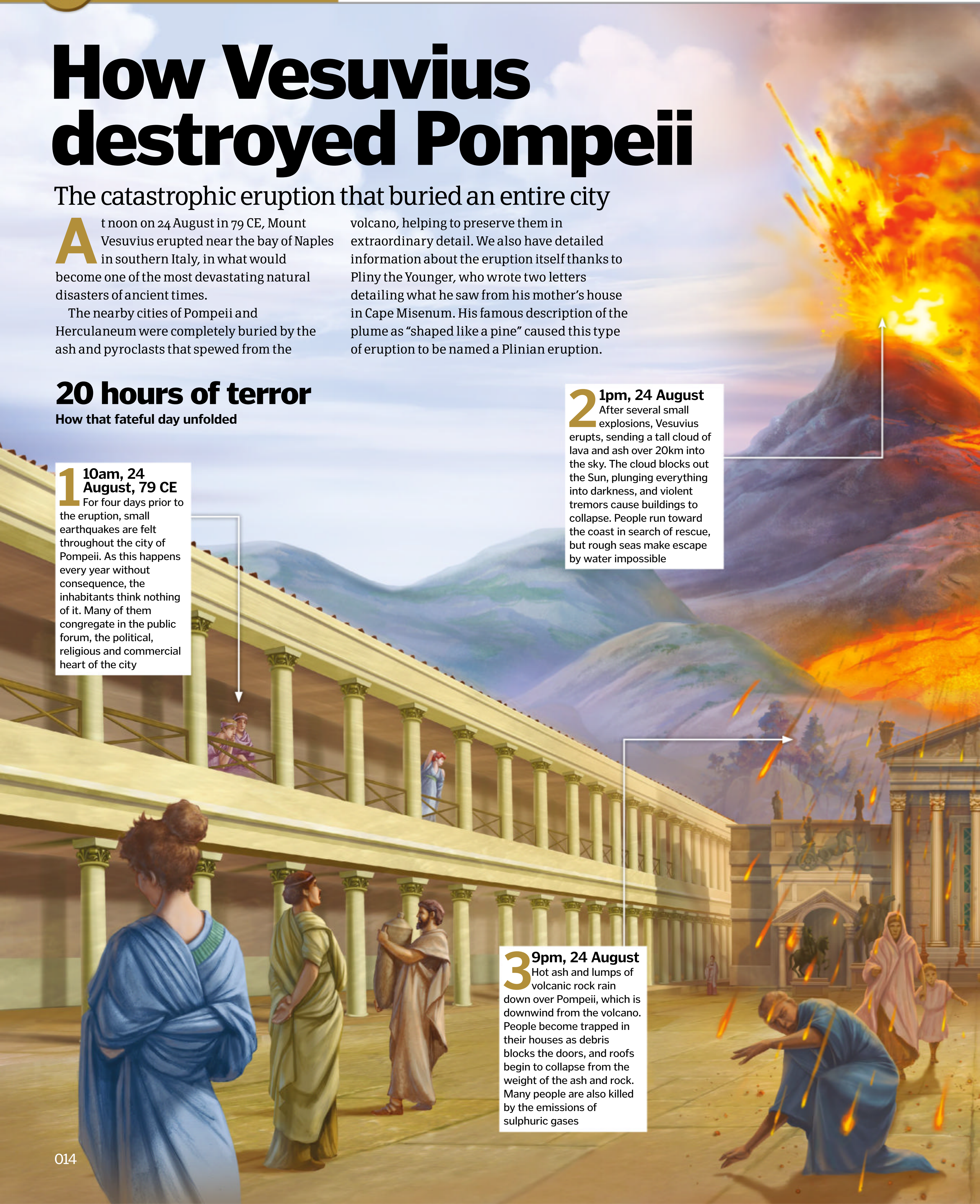
The catastrophic eruption that buried an entire city

At noon on 24 August in 79 CE, Mount Vesuvius erupted near the bay of Naples in southern Italy, in what would become one of the most devastating natural disasters of ancient times.

The nearby cities of Pompeii and Herculaneum were completely buried by the ash and pyroclasts that spewed from the volcano, helping to preserve them in extraordinary detail. We also have detailed information about the eruption itself thanks to Pliny the Younger, who wrote two letters detailing what he saw from his mother's house in Cape Misenum. His famous description of the plume as "shaped like a pine" caused this type of eruption to be named a Plinian eruption.

20 hours of terror

How that fateful day unfolded



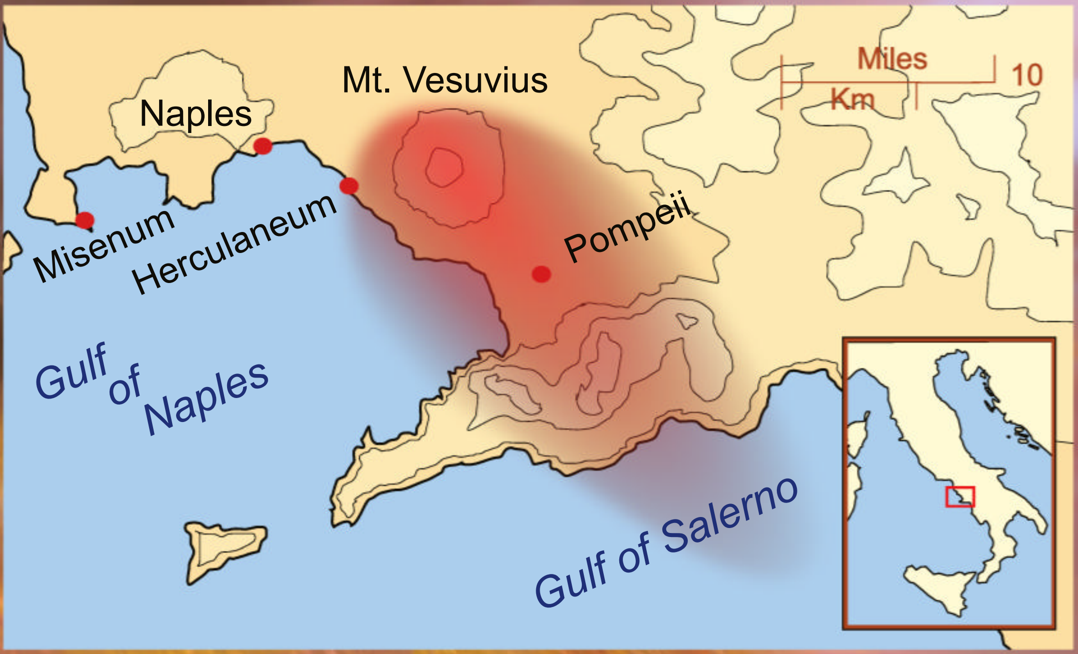
1 **10am, 24 August, 79 CE**
For four days prior to the eruption, small earthquakes are felt throughout the city of Pompeii. As this happens every year without consequence, the inhabitants think nothing of it. Many of them congregate in the public forum, the political, religious and commercial heart of the city

2 **1pm, 24 August**
After several small explosions, Vesuvius erupts, sending a tall cloud of lava and ash over 20km into the sky. The cloud blocks out the Sun, plunging everything into darkness, and violent tremors cause buildings to collapse. People run toward the coast in search of rescue, but rough seas make escape by water impossible

3 **9pm, 24 August**
Hot ash and lumps of volcanic rock rain down over Pompeii, which is downwind from the volcano. People become trapped in their houses as debris blocks the doors, and roofs begin to collapse from the weight of the ash and rock. Many people are also killed by the emissions of sulphuric gases

DID YOU KNOW? *The disaster of 79 CE was forgotten for hundreds of years – Pompeii wasn't excavated until 1748*

4 **12am, 25 August**
The ash cloud reaches its maximum height of 30km and then collapses, sending a pyroclastic surge of hot gas and rock down the volcano's northwest slope toward Herculaneum. Moving up to 700km/h and with temperatures up to 400°C, the surge instantly kills everyone it touches

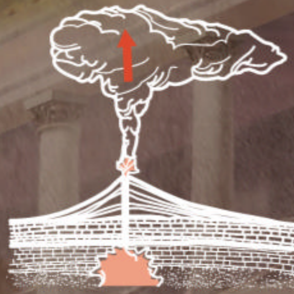


5 **6am, 25 August**
As dawn breaks, the cloud collapses for the last time, sending another pyroclastic surge toward Pompeii that kills everyone in its path. By the time the eruption is over, Pompeii is buried underneath five metres of volcanic material, while Herculaneum is buried under 20 metres

> *"By the time the eruption is over, Pompeii is buried underneath five metres of volcanic material"*

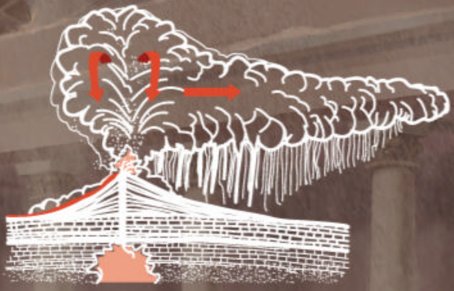
Anatomy of the eruption

Initial explosion



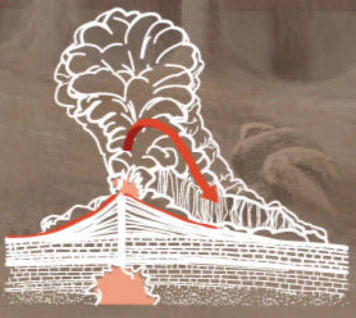
After more than 800 years of inactivity, pressure inside the volcano became too great. The built-up gases burst through the thick layer of lava that had plugged the crater and a column of ash climbs upward.

Spreading cloud



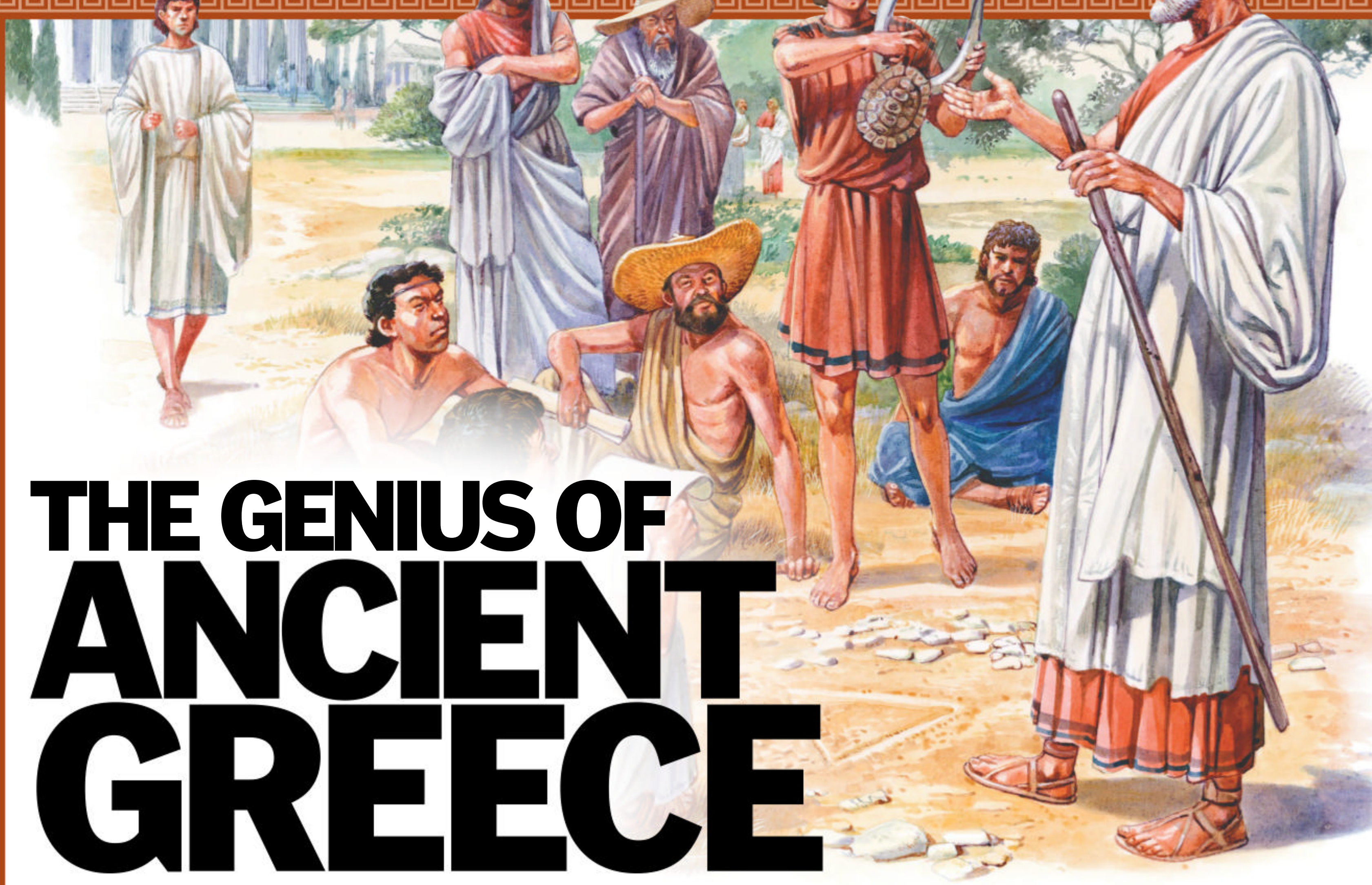
The wind blows the cloud toward the southeast, and it spreads to nearly 100km in width from side to side. Ash falls on Pompeii at a rate of 15cm per hour for an entire day.

Pyroclastic flows



As the ash cloud collapses, volcanic debris rolls down the sides of the volcano toward Herculaneum, which is 6km away, and Pompeii, which is 10km away. Anyone in the path of the flow had their body burned to the bone in seconds.

© Solgo



THE GENIUS OF ANCIENT GREECE

How the inventions, discoveries and culture of this great civilisation changed the world

Ancient Greece was pivotal for the development of Western culture and society. As Europe moved into the Iron Age, Greece was a leading light in the progression of ancient civilisation. Athens is often credited as the key player in this advancement, but other Greek states like Corinth, Thebes, and even the warlike Sparta, also contributed. Ancient Greece improved almost every facet of the economy, society, military and politics. The Greek phalanx was one of the most feared military formations in the ancient world; Greek theatres held the best plays, and athletes competed at the pinnacle of ancient sport: the Olympics.

Greek architects designed some of the finest ancient structures, and philosophers questioned the world in new ways. Homer's works *The Iliad* and *Odyssey* were unmatched in their time. Unlike civilisations before it, it's believed many educated people in ancient Greece were literate. Hundreds of words in the English language have their origins in the ancient Greek language such as 'encyclopaedia', 'telephone' and 'microscope'. The word 'democracy' is another, and it comes from the Greek 'demokratia', which means 'power to the people'.

Greek city-states were ruled by kings for the majority of the civilisation's history, but for a brief period around the 5th century BCE, Athens was a democracy. It wasn't the same system as we know it today (women and slaves weren't allowed to vote), but this incredibly important development has shaped world politics ever since, and anyone who can vote today owes it to the Greeks.

The divisions of the city-states curtailed scientific advancement as regions often fought among themselves. Finally unified under Alexander the Great in 336 BCE, Greek trade boomed and its culture spread throughout the Mediterranean, Asia Minor and North Africa. The Romans may have conquered Greece, but they were so impressed by its culture and technology, they copied Greek mythology, engineering, architecture and military tactics. The influence of ancient Greece is so important to the Western world that if it had been destroyed during its many conflicts with Persia, European civilisation could have turned out very differently.

Major events in ancient Greek culture

6000 BCE

First human settlement
The first Neolithic activity in Greece, including evidence of early agriculture.

2700 BCE

Minoan civilisation on Crete
The Minoan civilisation blooms under a system with no hierarchical structure.

1500 BCE

Mycenaean era
Greece is now in the Bronze Age and the Mycenaean culture develops the Greek language.

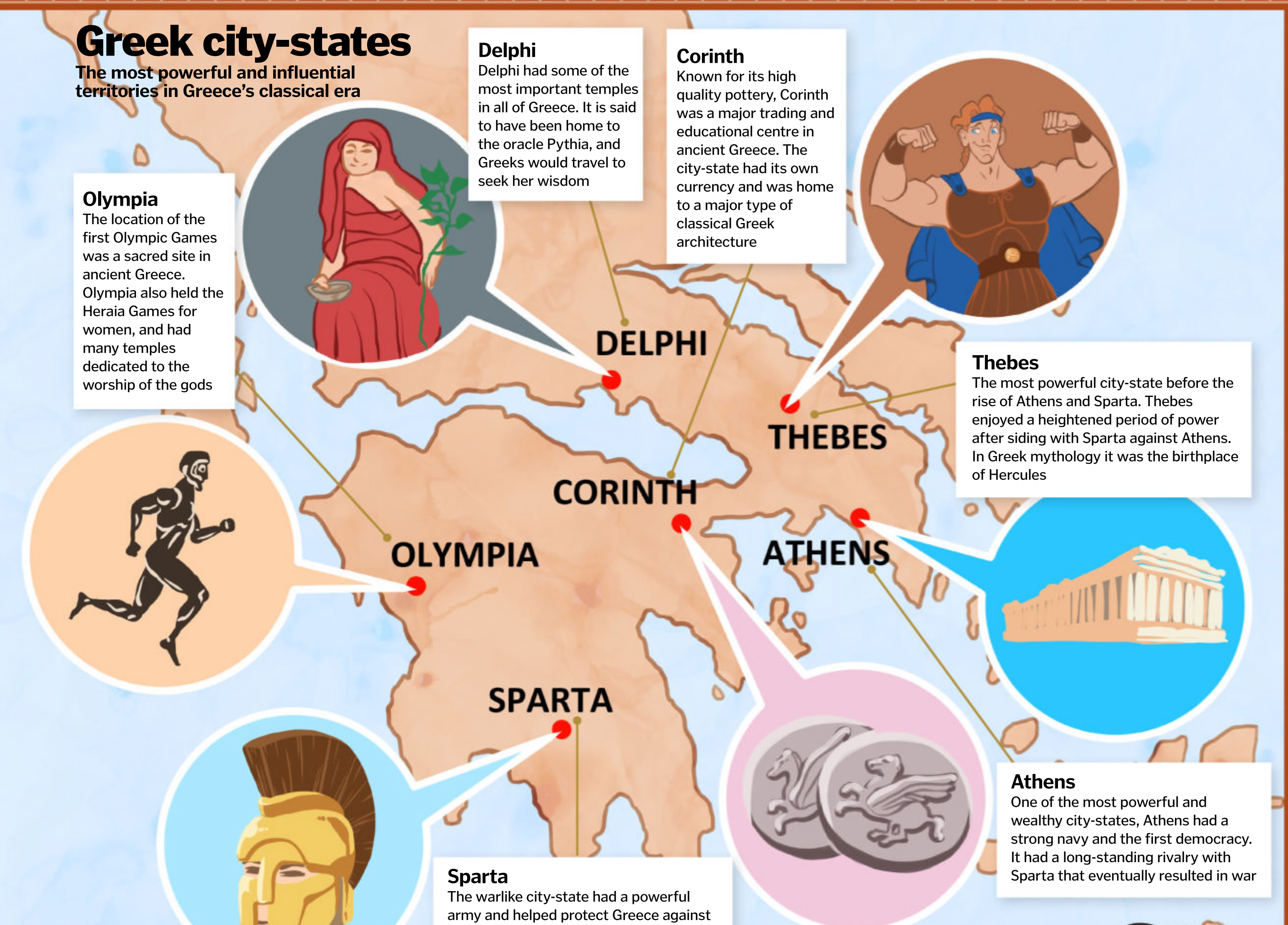
c.900 BCE

First pottery
Made in a classical geometric style, the first pottery unique to Greek culture is made.

DID YOU KNOW? *Plato was a talented wrestler and his name, which means 'broad shoulders', was given to him by his coach*

Greek city-states

The most powerful and influential territories in Greece's classical era



Olympia

The location of the first Olympic Games was a sacred site in ancient Greece. Olympia also held the Heraia Games for women, and had many temples dedicated to the worship of the gods

Delphi

Delphi had some of the most important temples in all of Greece. It is said to have been home to the oracle Pythia, and Greeks would travel to seek her wisdom

Corinth

Known for its high quality pottery, Corinth was a major trading and educational centre in ancient Greece. The city-state had its own currency and was home to a major type of classical Greek architecture

Thebes

The most powerful city-state before the rise of Athens and Sparta. Thebes enjoyed a heightened period of power after siding with Sparta against Athens. In Greek mythology it was the birthplace of Hercules

Athens

One of the most powerful and wealthy city-states, Athens had a strong navy and the first democracy. It had a long-standing rivalry with Sparta that eventually resulted in war

Sparta

The warlike city-state had a powerful army and helped protect Greece against the Persians. Every male citizen was a warrior, taught from age seven, to form a professional and widely-feared army

Macedonian unification of Greece

The Peloponnesian Wars (431-404 BCE) tore Greece apart, with the hegemony of Athens broken by Sparta and its allies. Greece remained divided, with a series of uneasy alliances leaving it weak and open for invasion. Around this time the power of Macedonia was growing and King Philip II of Macedon took advantage of a weakened Greece. His army defeated a strong alliance of Athenian and Theban soldiers at the decisive Battle of Chaeronea in 338 BCE. Sparta did not join in the battle but would also later be defeated. Philip was now the undisputed ruler of Greece, and although he was later assassinated, this brought his son Alexander III to the throne. A born leader, Alexander the Great unified Greece under his rule and made it his intention to bring the Persian Achaemenid Empire to its knees. Alexander went on to lead one of the most powerful empires in the ancient world, which stretched from Greece in the west to India in the east.

Philip and Alexander's rule united Greece and established it as a major military power

ARCHAIC PERIOD

c.800 BCE

Works of Homer

The 'blind bard' writes the poems *The Iliad* and *Odyssey.*

776 BCE

Olympic Games held

The first Olympics take place as a festival dedicated to Zeus. The event is held every four years for centuries.

740 BCE

Greek alphabet

Created from a Phoenician script, evidence of the first Greek alphabet is found.

700 BCE

Birth of musical study

Sparta and Argos hold the first organised studies of musical theory and the first documented musical competitions.

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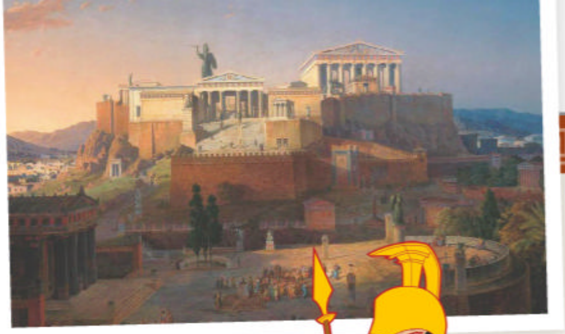
The Acropolis

Athens' defining citadel became an enduring symbol of ancient Greek architecture

Many major Greek cities were dominated by an Acropolis at their centre. Meaning 'high city', it was a well-defended hill that citizens would retreat to when the city was under attack. The city-states of Thebes and Corinth both had an Acropolis, but by far the most famous of these citadels stood in the centre of Athens. The original structures were improved after victory at the Battle of Marathon in 490 BCE, but were destroyed by Xerxes' Persian troops when they sacked Athens ten years later.

After the Persian defeat at Salamis, the city used its wealth to restore splendour to the Acropolis. Vast building projects got underway and the area became a huge centre of worship for the goddess Athena, the patron deity of Athens.

The grandest temple of all was the Parthenon, which was constructed between 447 and 432 BCE. It housed a magnificent ivory statue of Athena and was the store of the city's gold reserves. The area became a place of worship and culture rather than just defence, with the temples of Athena Nike, Erechtheion and Propylaia also built in a 50-year period. With the help of modern restoration efforts, the Parthenon stands above the city to this day.

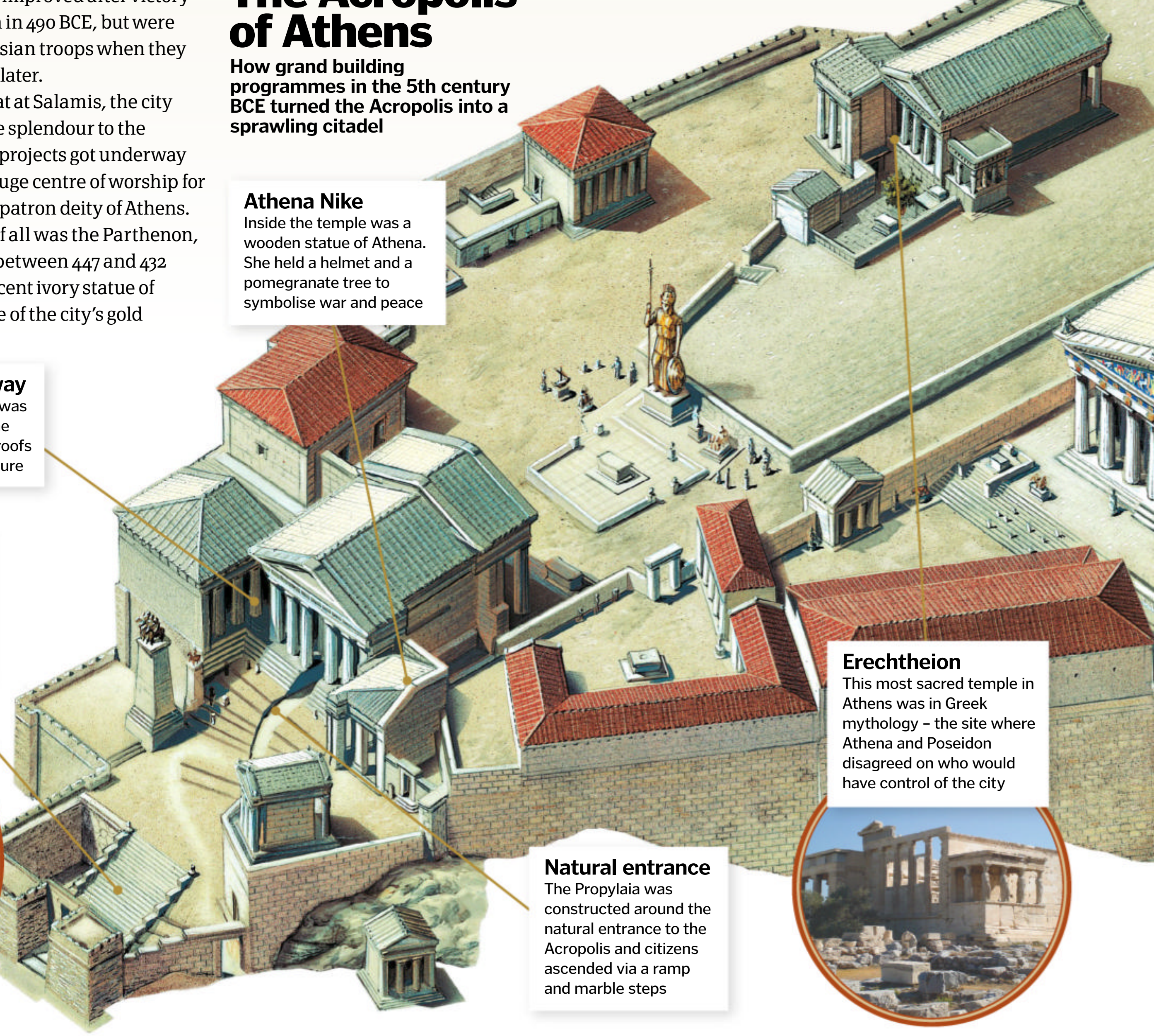


The Acropolis rises 150 metres above Athens and is around six hectares in size

> "The area became a huge centre of worship for the goddess Athena"

The Acropolis of Athens

How grand building programmes in the 5th century BCE turned the Acropolis into a sprawling citadel



Athena Nike
Inside the temple was a wooden statue of Athena. She held a helmet and a pomegranate tree to symbolise war and peace

Monumental gateway
Known as a Propylaia, this was a decorative entrance to the complex. Its columns and roofs made it an imposing structure

Acropolis entranceway
The main entrance to the Acropolis was a wide stone staircase that led to the monumental gateway

Erechtheion
This most sacred temple in Athens was in Greek mythology – the site where Athena and Poseidon disagreed on who would have control of the city

Natural entrance
The Propylaia was constructed around the natural entrance to the Acropolis and citizens ascended via a ramp and marble steps

625 BCE

Advancements in pottery
Black figure pottery becomes popular in Greece, but is later superseded by red figure pottery.

621 BCE

Draco's code of law
Devised by an Athenian aristocrat, these became the city's first written law codes and legal system.

594 BCE

First coins
Athens now uses a currency as trade and industry begin to develop.

508 BCE

Birth of democracy
'The father of Athenian Democracy', Cleisthenes introduces a new political system as the public become involved in politics.

CLASSICAL PERIOD

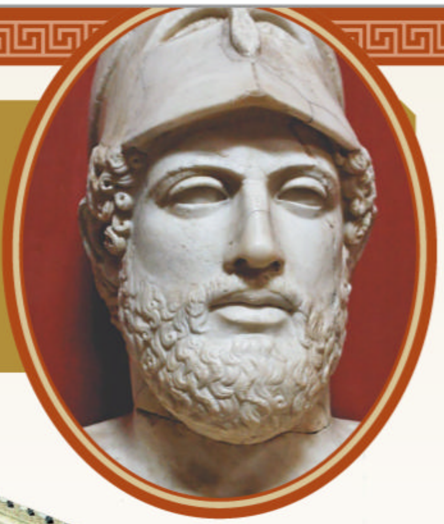
DID YOU KNOW? *The ancient Greeks invented the first type of vending machine. It was coin-operated and dispensed holy water*

The Parthenon

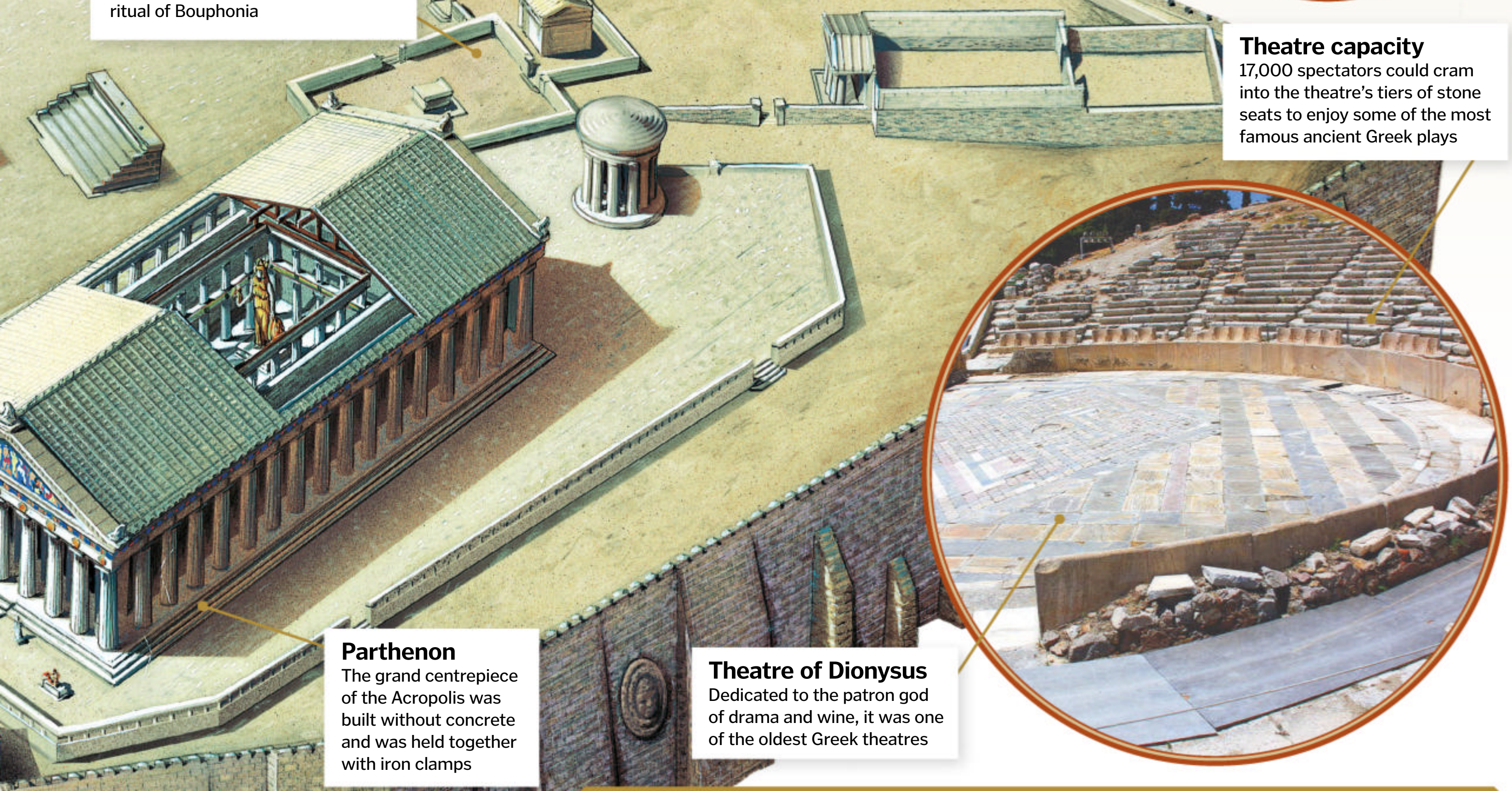
The popular Athenian general and statesman Pericles was the driving force behind the reconstruction of the Acropolis after it was destroyed by the Persians.

Pericles wanted the citadel to be larger and grander than ever before. The project was an expensive venture and Pericles skillfully used tributes paid to the city to fund it. Many of the finest architects and sculptors of the ancient world, along with hundreds of labourers, contributed.

Pericles is remembered as a hero of Athens and shortly after his death from the plague, the city lost the Peloponnesian Wars against Sparta and entered a period of cultural darkness.



Under Pericles' leadership the city entered a golden age of prosperity



Sanctuary of Zeus Polieus
An open-air sanctuary with a small barn nearby, oxen were sacrificed to Zeus here once a year in the annual ritual of Bouphonia

Theatre capacity
17,000 spectators could cram into the theatre's tiers of stone seats to enjoy some of the most famous ancient Greek plays

Parthenon
The grand centrepiece of the Acropolis was built without concrete and was held together with iron clamps

Theatre of Dionysus
Dedicated to the patron god of drama and wine, it was one of the oldest Greek theatres

The Panathenaic Games

The most important of all the Athenian festivals was the Panathenaea. A rival to the Olympic Games, it was celebrated every four years and held all over the city for around a week between July and August. The Games were based around three types of contests: musical, gymnastic and equestrian, and included hoplite races in full armour and pankration (a brutal mix of wrestling and boxing). The event was organised by ten administrators called the Athlothetai, and men, women and children all competed in the events, from professional athletes to freed slaves. The winners were mostly presented with valuable prize amphoras, which they often sold for coin. Champions gained so much money that they could make a career out of participating in these festivals.

The Games held a pentathlon including running, javelin, discus and long jump

483 BCE

Mining precious metals

Athens establishes silver mines, which allow Themistocles to create a fleet to defeat the Persians at Salamis.

468 BCE

Development of the theatre

Tragedian Sophocles writes plays for theatre, which become immensely popular.

447 BCE

Building the Parthenon

Construction begins on the Parthenon, a temple dedicated to Athena, the goddess of wisdom and war.

420 BCE

Atomic theory of matter

Philosopher Democritus hypothesises the existence of atoms and different types of matter.

© Solgo; WIKI; Thinkstock; DK

Innovations and inventions

The ancient Greeks devised many clever mechanisms and systems that are still used today

From the Olympics to democracy, Greek civilisation had a huge impact on the West. The Babylonians may have created the first maps, but it was the Greeks who pioneered the study of cartography. Philosopher Anaximander drew up the first world map, which was divided into two sections: Europe and Asia. The Greeks also revolutionised the field of geometry with Pythagoras' theorem and the refined value of pi.

Before the Greeks, ancient civilisations blamed disease on the wrath of gods. While the Greeks still believed in divine retribution, physicians like Hippocrates observed patients suffering with conditions and recorded signs and symptoms. This helped to advance surgery, anatomy and public health. There was also progress in the knowledge of the natural world, with the differences in plants documented for the first time. Greek thinking also resulted in inventions like the buckle, metal anchors and the crane.

City-states like Athens were built to a set plan. Surveyors devised streets and squares with enough room for theatres, markets and temples. This is one of the first recorded instances of urban planning, and provided cities with space and facilities. Multiple urban areas were based around the Hippodamian Plan: a city in a rectangular grid – helpful for navigating and organising the streets for both economic and defensive reasons.

Perhaps the most obvious relic of ancient Greece today is its architecture. Ionic and Doric columns are still used on many neoclassical buildings around the world, such as the US Capitol building and the Arc de Triomphe.

Even after the fall of ancient Greece, its legacy lived on. The Roman Empire was inspired by Greek mythology and built upon many Greek ideas of geometry, astronomy and culture.

Other Greek inventions

Inventions we still use today, from the shower to the alarm clock

Alarm clock
They worked by using a dial to indicate the time, which would sound with the drop of pebbles onto drums.

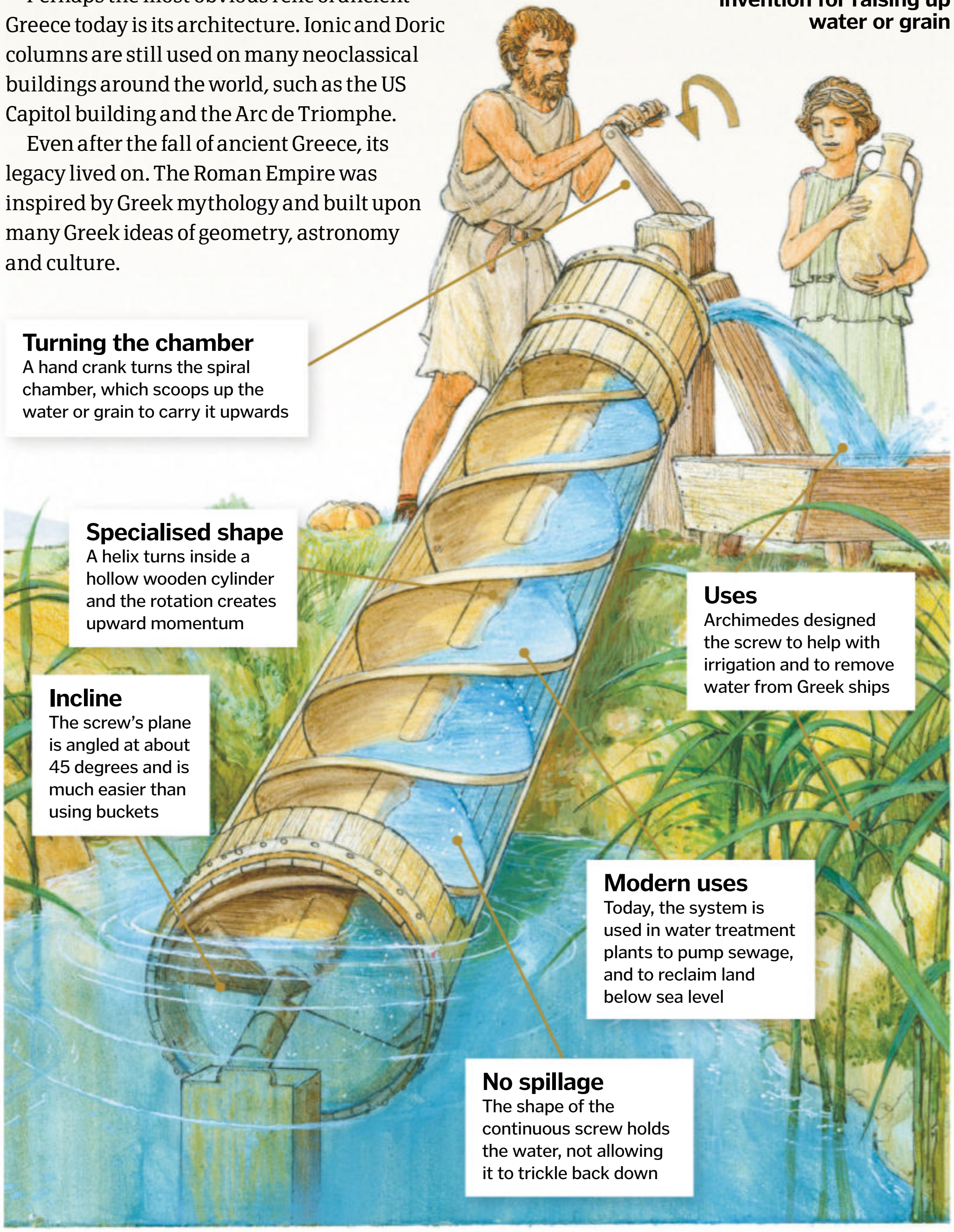
Water mill
The water mill ground grain to produce rice, flour, lentils and cereals, important for feeding the population.

Odometer
This mechanical instrument measured distance and was used by the Romans to help build their roads.

Shower
The Greeks were the first to use piped water to shower themselves. The showers were fed by a plumbing system.

The Archimedes' screw

The physics of Archimedes' screw, an ingenious Greek invention for raising up water or grain



Turning the chamber
A hand crank turns the spiral chamber, which scoops up the water or grain to carry it upwards

Specialised shape
A helix turns inside a hollow wooden cylinder and the rotation creates upward momentum

Uses
Archimedes designed the screw to help with irrigation and to remove water from Greek ships

Incline
The screw's plane is angled at about 45 degrees and is much easier than using buckets

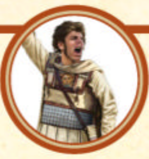
Modern uses
Today, the system is used in water treatment plants to pump sewage, and to reclaim land below sea level

No spillage
The shape of the continuous screw holds the water, not allowing it to trickle back down

380 BCE
The Athens Academy
Plato opens the first Western higher learning centre to educate students on mathematics and science.

c.359 BCE
Invention of the catapult
An early stone-throwing siege machine is invented in 4th century BCE, and becomes a commonplace weapon in large scale conflict.

336 BCE
Alexander the Great
The Macedonian king Alexander spreads Greek language and culture through Asia via an expansive and formidable empire.



335 BCE
Aristotle's lyceum
Alexander's tutor founds a school to rival Plato's that lectures students on physics and biology.

HELLENISTIC PERIOD

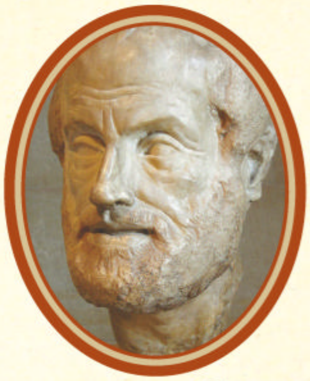
DID YOU KNOW? *The first Olympics in 776 BCE only had one event, the 200 metres. It was won by a baker called Coroebus*

Great Greek minds

Meet some of the most prominent thinkers in all of ancient Greece

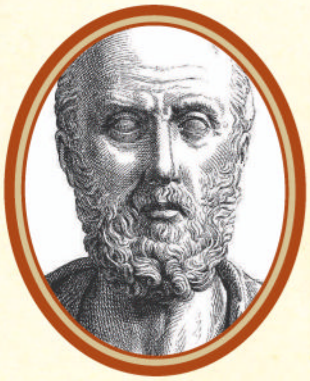
HIPPOCRATES

Hippocrates was one of the first to observe the effect diseases had on the body. He separated medicine from religion, and by recording what he saw – whether it was a pale face or dry skin – he helped develop methods to prevent and cure diseases.



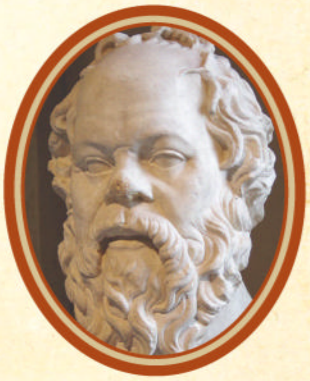
SOCRATES

Socrates was a renowned philosopher, and Socratic teaching concentrated on asking questions, fostering debate and forming ideas through conversation. The Socratic method is still used by educators today to encourage their students to think critically.



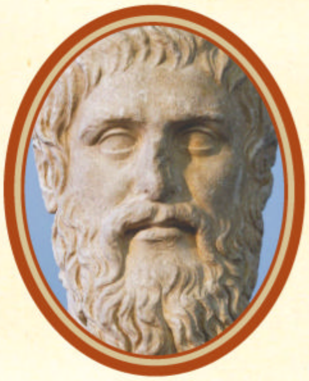
ARISTOTLE

The so-called father of logic wrote over 150 works and spoke on the topics of philosophy and biology like no other. He believed that existence was based on achieving personal happiness.



EUCLID

A leading mathematician, Euclid wrote 13 books known as *The Elements*, which collected 300 years worth of ancient ideas on geometry. Euclid made these earlier works accessible to many and it has become incredibly influential in teaching.

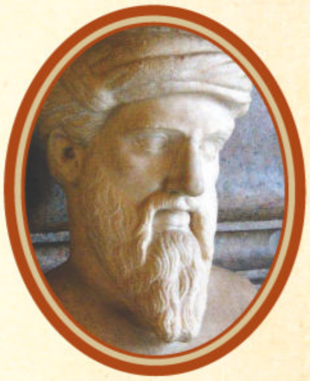


PYTHAGORAS

Known as the father of numbers, Pythagoras is world-renowned for his eponymous theorem for deducing the length of the third side of a triangle. Many works were published in his name by his loyal followers.

PLATO

The teacher of Aristotle was a student of Socrates who spread his mentor's teachings. He lends his name to the idea of Platonic love and founded the first higher learning institute in the West.



What the Greeks did for us

The legacy of ancient Greece in the 21st century

Olympics

Dedicated to Zeus, the Olympic Games first took place in 776 BCE.

Hippocratic oath

This sacred oath was written by Hippocrates and promises that a doctor will do everything they can to help their patient.

PEER JURY

The justice system and the concept of a trial were advanced in Athens.

Philosophy

The Greeks were the first to constantly question the world and develop new scientific methods of thought.

Theatre

Both dramas and comedies were performed in front of audiences.

SPHERICAL EARTH THEORY

Pythagoras was the first person to propose that the Earth was a sphere after observing our round Moon.

Democracy

For a time, male Athenian citizens had equal political rights and freedom of speech.

Aα
Bβ

Language

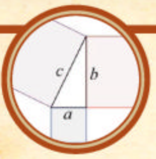
The ancient Greek writing system inspired the Latin alphabet and is still in use.

> *"City-states like Athens were built to a set plan"*

c.300 BCE

Mathematical advancements

Mathematician Euclid writes *The Elements*, an influential collection of 13 textbooks on geometry, which included work on Pythagorean theorem.



c.250 BCE

Archimedes' screw

The great Greek polymath Archimedes conceives the Archimedes' screw, just one of his many inventions.

238 BCE

Syracuse theatre

A popular Greek theatre is expanded significantly into one of the largest known in the ancient world.

146 BCE

Roman Greece

The Romans invade Greece. Impressed by Greek architecture, cities become tourist attractions and many customs are copied.

© Thinkstock; WIKI

The art of mummification

Mummies have been found in many parts of the world, but Egyptian mummies are the most well-known due to their distinctive appearance and unique embalming process

Ancient Egyptians used to bury their dead directly in the hot sand, which dried and preserved them somewhat. When they began using caskets, the bodies decayed instead. Around 2600 BCE, Egyptians began experimenting with a way to preserve their ancestors. They learned that bodies decayed from the inside out, starting with their organs. Embalmers perfected a process by which the organs were removed and the body dried prior to burial. This practice, known as mummification, was used for nearly 3,000 years.

Mummification was an expensive process and could take up to 70 days to complete. The embalmers worked in open tents, out in the desert and away from the general population. After washing the body, they removed the brain from the skull. In order to get into the brain cavity, embalmers put a chisel up the body's nose and hit it with a hammer to crack through the bone. Then, they inserted a long hook to pull out brain matter.

After cutting a slit in the left side of the body, embalmers removed the abdominal organs. They were washed, wrapped in linen and packed in jars. Natron, a naturally occurring salt, was added as a drying agent. The body was rinsed with wine and filled with incense and natron, then covered with more natron. A slanted table allowed fluids to drip from the body as it dried while guards kept away scavengers. Once the body was dry, embalmers wrapped it in linen strips in several stages and coated it with resin. The linen helped keep the body together and prevented moisture from entering. A rigid scaffold was then fitted over the body and a funeral mask attached to the face. Finally, the completed mummy was placed into a container decorated to look like a person, called a suhet.

An extreme way of wrapping up warm for winter

© Thinkstock

> "The practice of mummification was used for nearly 3,000 years"

© 2005 David Monniaux

Britain's tribal territories

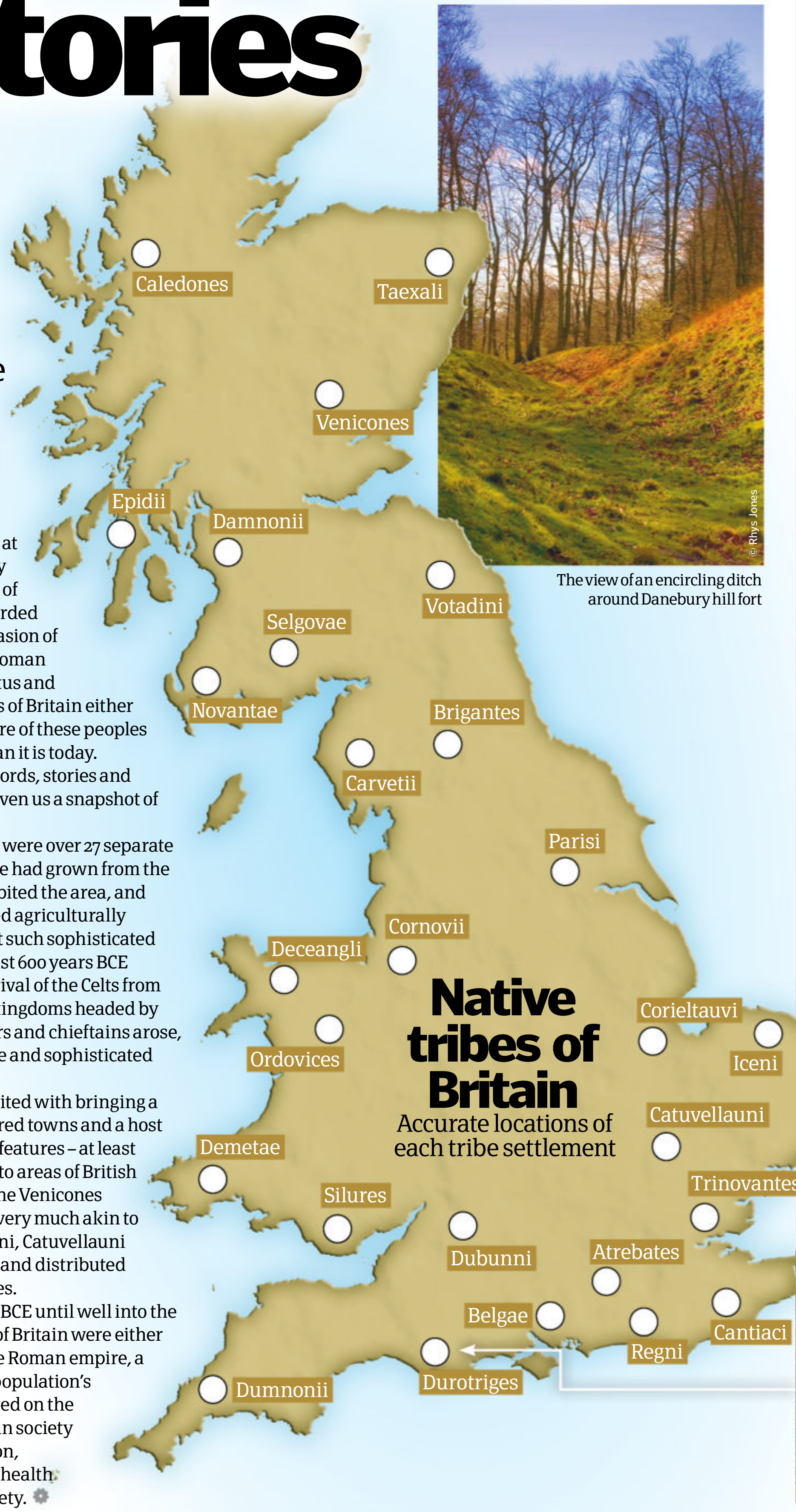
Before the Roman invasion in 55 BCE, Britain was characterised by a large number of ancient tribes, each with its own culture

While the first modern humans populated the area we now call Britain at the end of the Ice Age (6,500 BC), very little is known about the intricacies of their culture and peoples until recorded history begins circa the Roman invasion of 55 BC. Indeed, if it were not for the Roman chroniclers of the time such as Tacitus and Ptolemy, who met the ancient tribes of Britain either in trade or in war, our sketchy picture of these peoples would be even more incomplete than it is today. However, centuries of historical records, stories and archaeological finds have at least given us a snapshot of their lives, leaders and customs.

Before the Roman invasion there were over 27 separate tribes living in Britain. These people had grown from the early hunter-gathers who had inhabited the area, and later the farmers who had developed agriculturally focused societies and who had built such sophisticated structures as Stonehenge. For the last 600 years BCE though, influenced much by the arrival of the Celts from the continent, expansionist tribal kingdoms headed by dynastic and highly territorial rulers and chieftains arose, delivering cultures of fierce violence and sophisticated manufacture, artistry and trade.

While the Romans are often credited with bringing a unified currency, as well as structured towns and a host of amenities and technology, these features – at least in part – were already integrated into areas of British tribal society. Some tribes such as the Venicones buried their dead in stone casings, very much akin to a tomb or coffin. Others, like the Iceni, Catuvellauni and Atrebates, had already created and distributed currency throughout their territories.

Over 200 years, however, from 55 BCE until well into the 2nd Century AD, the ancient tribes of Britain were either conquered or indoctrinated into the Roman empire, a process that largely converted the population's attitudes and cultures to those shared on the continent and saw a gradual climb in society towards standards of administration, architecture, sanitary systems and health care that resonate with today's society.



Native tribes of Britain

Accurate locations of each tribe settlement

© Rhys Jones

The view of an encircling ditch around Danebury hill fort

Head to Head
ANCIENT BRITISH TRIBES

MOST REBELLIOUS

© PHGCOM

1. Iceni

Located: Norfolk

Facts: One of the most rich and powerful tribes in Britain, the Iceni revolted against the Romans after the death of their client-king Prasutagus and were lead until her death by Prasutagus' wife, the renowned Queen Boudicca.

MOST CIVILISED

© John Opie

2. Catuvellauni

Located: South-east

Facts: One of the most pro-Roman tribes, the Catuvellauni quickly adopted Roman lifestyles and, as a result, were made very rich and powerful. One of the most famous British tribal kings, Cunobelinus, originally heralded from the Catuvellauni.

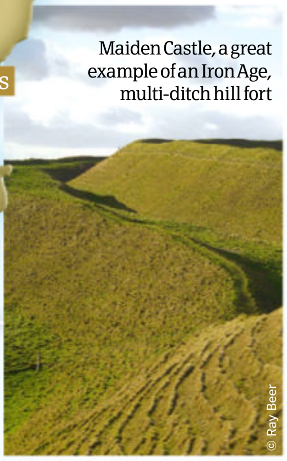
MOST DEFENSIVE

© Nigel Mykura

3. Durotriges

Located: Dorset

Facts: A southern tribe, the Durotriges differed from others by remaining largely in hill forts long after others had abandoned them. They were huge traders and, through numerous harbours, exchanged many goods with the Romans.



Maiden Castle, a great example of an Iron Age, multi-ditch hill fort

© Ray Beer

The Terracotta Army

Learn about China's ancient warriors for the afterlife

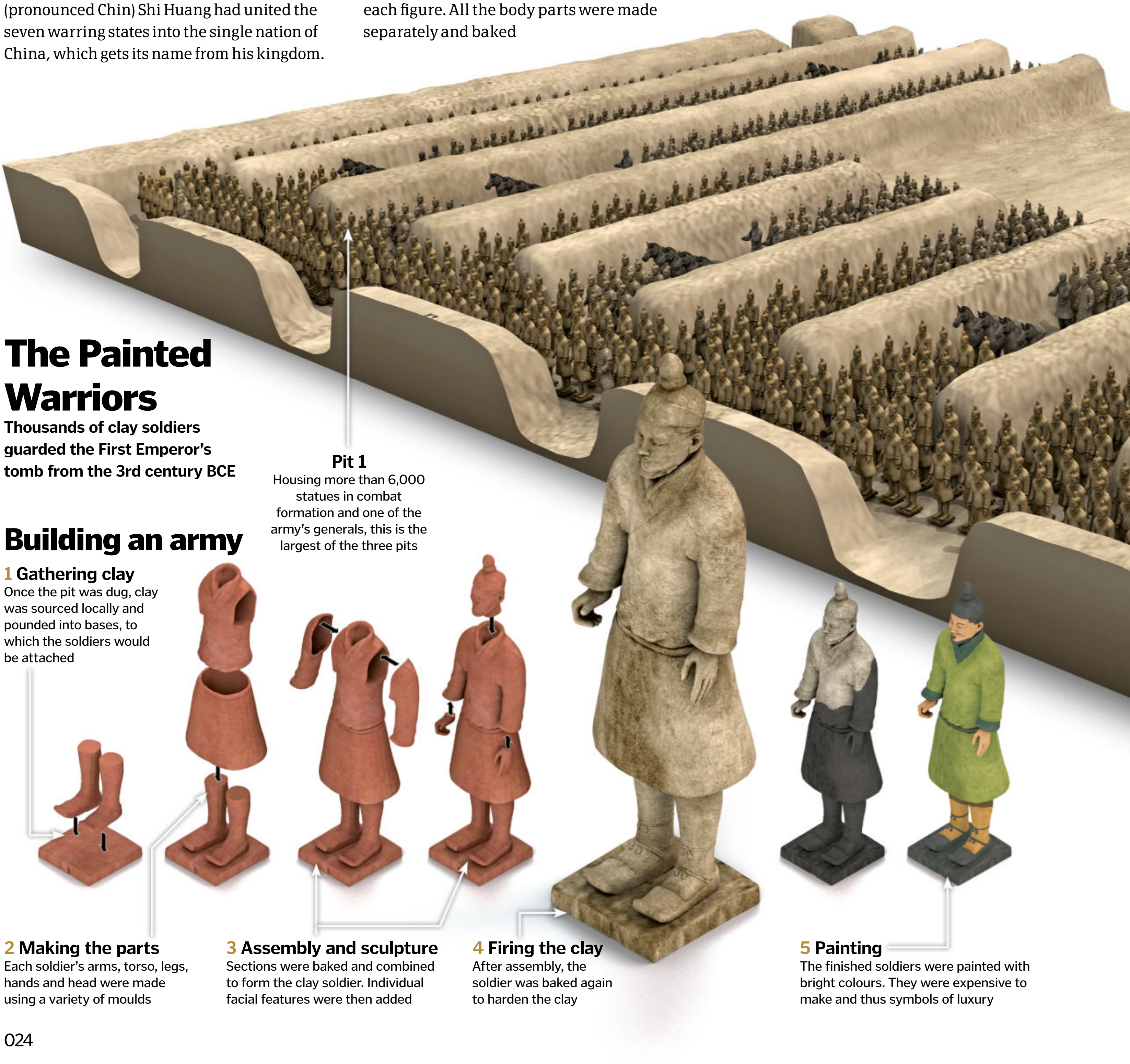
The eighth wonder of the ancient world was discovered by accident. In 1974 in Xi'an, China, a group of farmers were digging when they uncovered a pit containing thousands of life-size warrior statues. The Terracotta Armyis part of an enormous mausoleum, built to accompany the First Emperor into the afterlife.

Over 2,000 years ago, Emperor Qin (pronounced Chin) Shi Huang had united the seven warring states into the single nation of China, which gets its name from his kingdom. The resulting peace meant there was no use for his vast army, so he set them to work building his elaborate tomb.

Much like the whole of Chinese society at the time, the Emperor was obsessed with life after death. He believed that the next world mirrored this one, so commissioned an army of life-size clay warriors to help maintain his rule. The pits were excavated and clay bases were made for each figure. All the body parts were made separately and baked in a kiln before being joined, in an impressive early example of assembly-line construction. Once complete, each warrior was baked again at 1,000 degrees Celsius to harden the final structure. These advanced methods make that the Terracotta army is a lasting reflection of the ingenuity of early Chinese society.

The Painted Warriors

Thousands of clay soldiers guarded the First Emperor's tomb from the 3rd century BCE



Pit 1
Housing more than 6,000 statues in combat formation and one of the army's generals, this is the largest of the three pits

Building an army

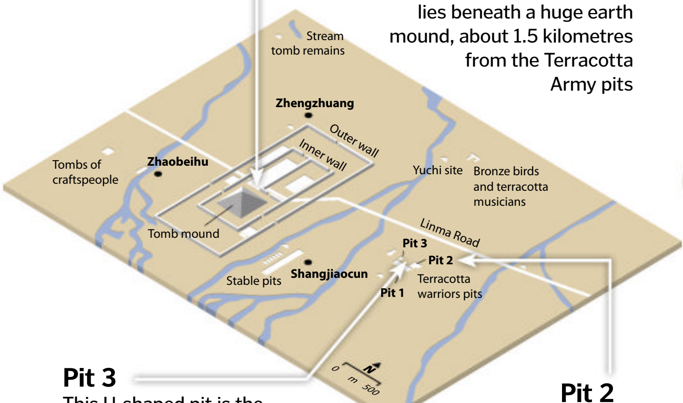
1 Gathering clay
Once the pit was dug, clay was sourced locally and pounded into bases, to which the soldiers would be attached

2 Making the parts
Each soldier's arms, torso, legs, hands and head were made using a variety of moulds

3 Assembly and sculpture
Sections were baked and combined to form the clay soldier. Individual facial features were then added

4 Firing the clay
After assembly, the soldier was baked again to harden the clay

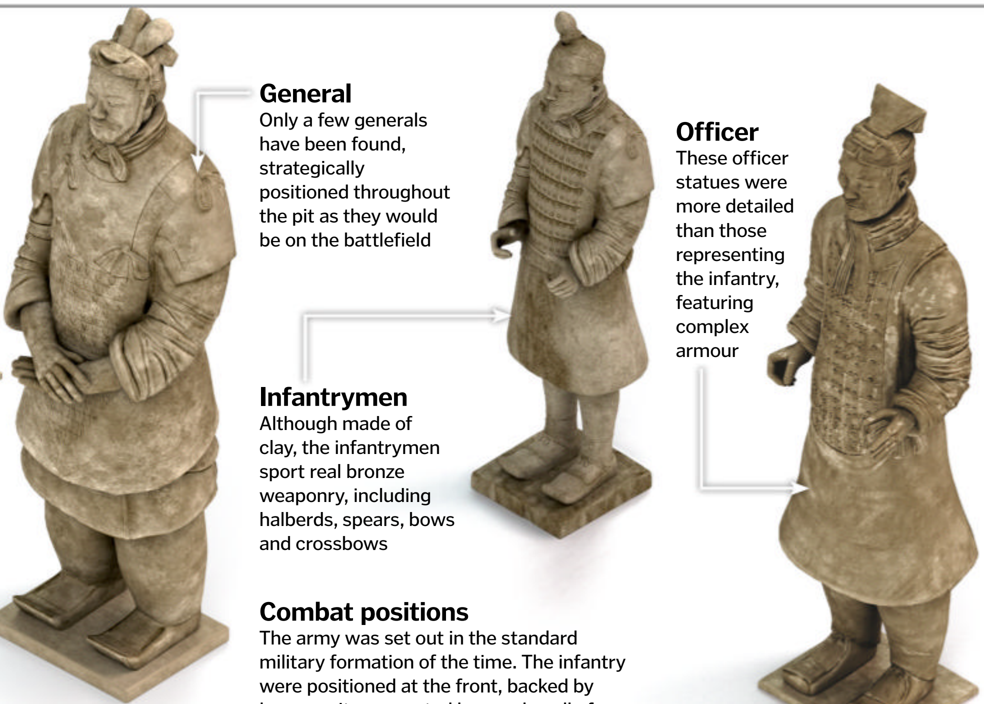
5 Painting
The finished soldiers were painted with bright colours. They were expensive to make and thus symbols of luxury


Stream
tomb remains
Zhengzhuang
Outer wall
Inner wall
Tombs of craftspeople
Zhaobeihu
Yuchi site
Bronze birds and terracotta musicians
Tomb mound
Linma Road
Pit 3
Pit 2
Stable pits
Shangjiaocun
Pit 1
Terracotta warriors pits
0 m 500
N

The mausoleum
The First Emperor's tomb lies beneath a huge earth mound, about 1.5 kilometres from the Terracotta Army pits

Pit 3
This U-shaped pit is the smallest, housing fewer than 100 soldiers, four horses and a chariot

Pit 2
Featuring some 80 chariots and an array of weaponry, this pit also contains some 160 kneeling archers

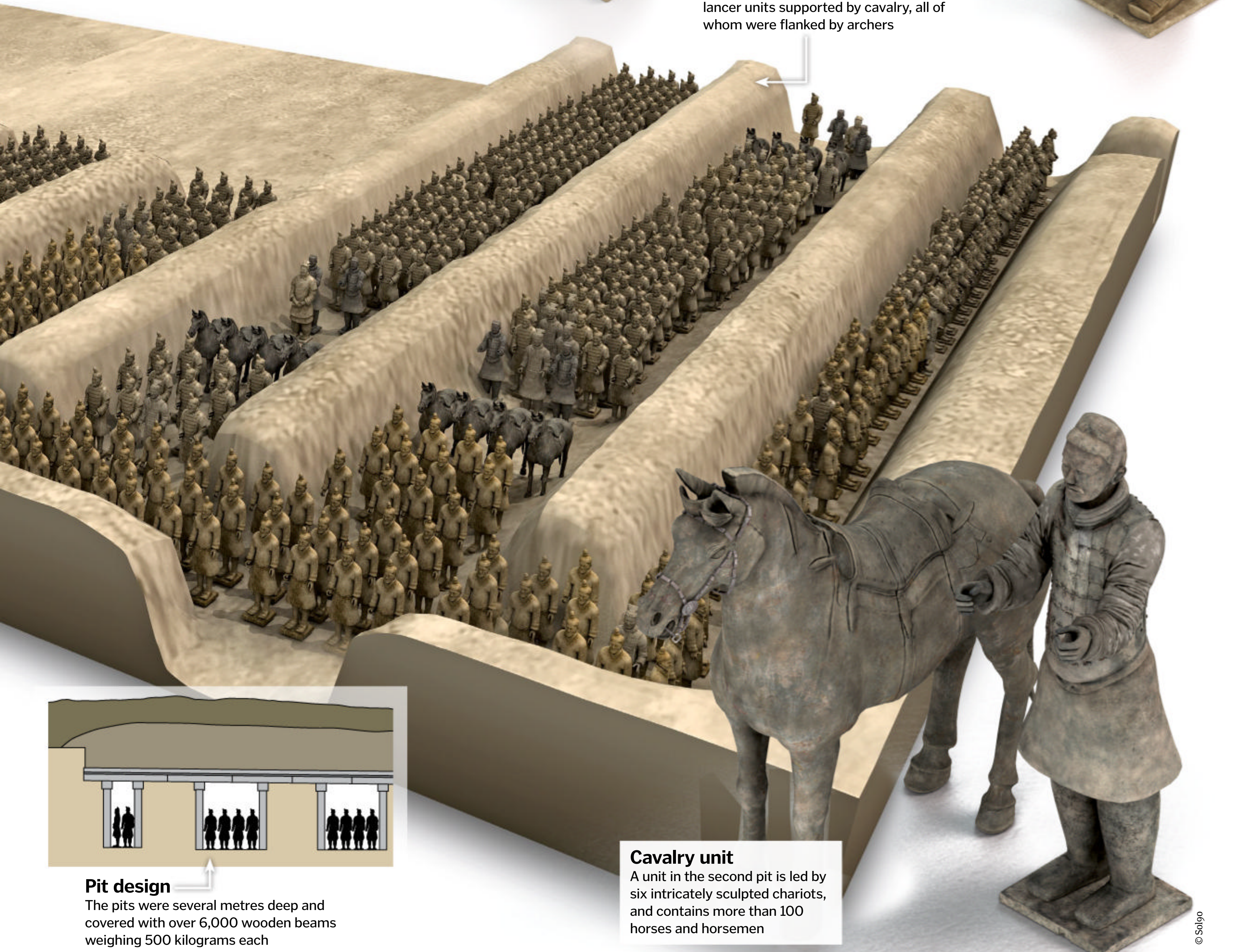


General
Only a few generals have been found, strategically positioned throughout the pit as they would be on the battlefield

Infantrymen
Although made of clay, the infantrymen sport real bronze weaponry, including halberds, spears, bows and crossbows

Officer
These officer statues were more detailed than those representing the infantry, featuring complex armour

Combat positions
The army was set out in the standard military formation of the time. The infantry were positioned at the front, backed by lancer units supported by cavalry, all of whom were flanked by archers



Pit design
The pits were several metres deep and covered with over 6,000 wooden beams weighing 500 kilograms each

Cavalry unit
A unit in the second pit is led by six intricately sculpted chariots, and contains more than 100 horses and horsemen

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BUILDINGS, PLACES & LANDMARKS

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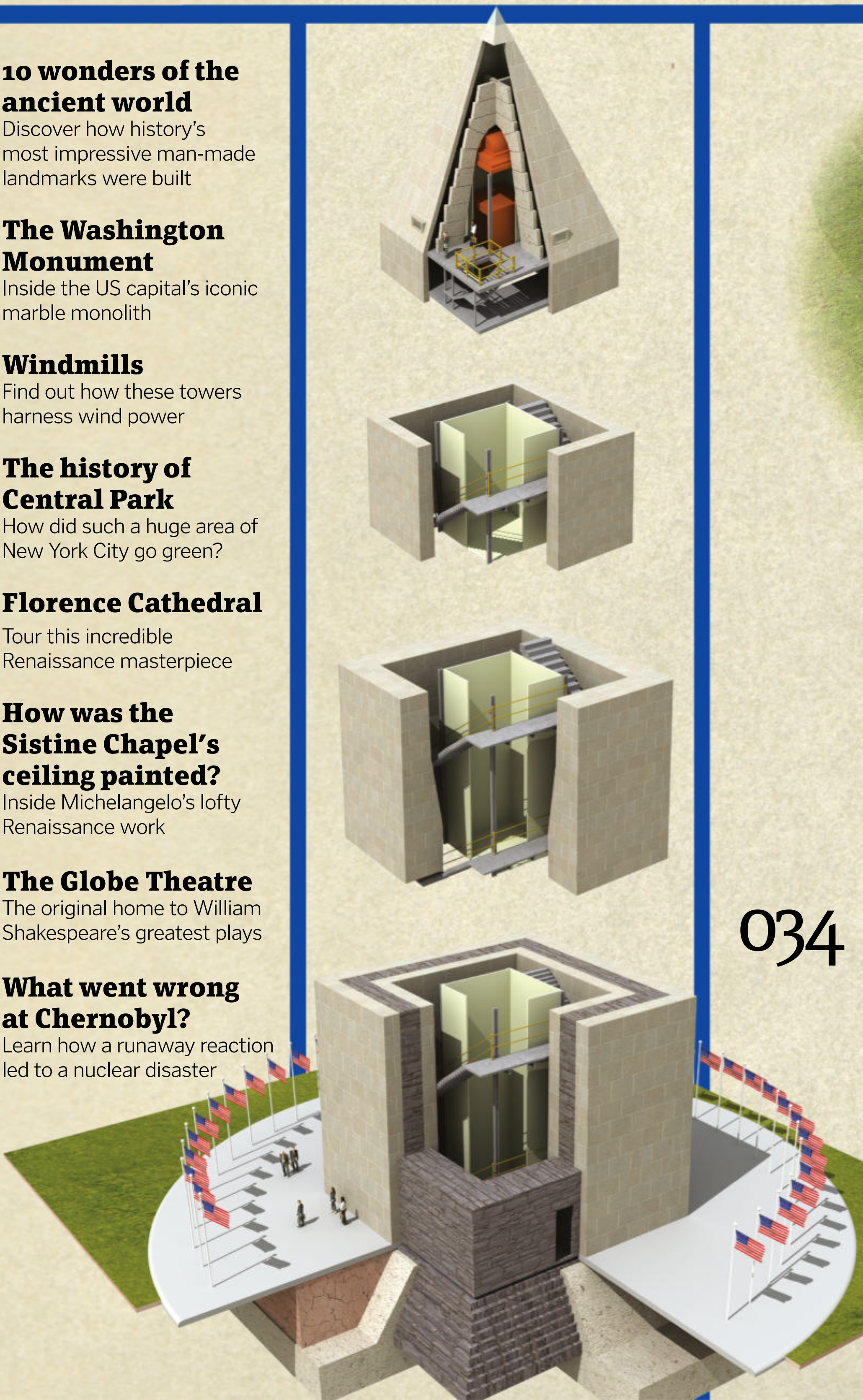

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10 WONDERS OF THE ANCIENT WORLD

Take a tour of history's greatest human-made landmarks and discover how they were built

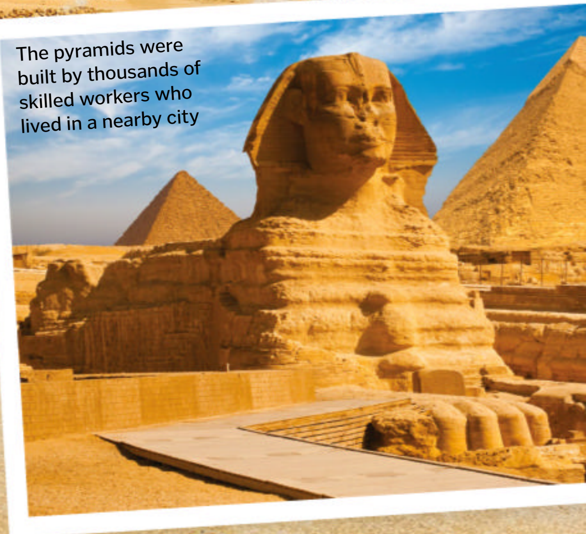
The Pyramids of Giza and the Sphinx

The mystery of ancient Egypt's monumental feat of engineering

Built between 2589 and 2504 BCE, the three Pyramids of Giza served as extravagant tombs for ancient Egyptian pharaohs, large enough to house everything they would require in the afterlife.

The largest, constructed for the Pharaoh Khufu, consists of 6.5 million tons of stone, some in blocks as heavy as nine tons each. However, no one quite knows how they were moved into position.

One theory is that a system of sledges, rollers and levers were used to haul the blocks up a slope that was increased in height as the pyramid grew. Meanwhile, the Sphinx, which stands close to the pyramids, was carved out of the limestone bedrock of the Giza Plateau.



The pyramids were built by thousands of skilled workers who lived in a nearby city

The Great Wall of China

Incredible manpower and tasty materials helped construct the world's longest wall

Although the first sections of border walls had been built in the 8th century BCE, it wasn't until 220 BCE that Emperor Qin ordered for them to be joined up as a protective barrier. He set 300,000 soldiers plus many more peasants and prisoners to work constructing the wall from stone, soil, wood and even sticky rice, which was used to help hold the bricks together. The materials were transported to the site by hand or using wheelbarrows, ropes and animals.

Approximately 400,000 workers died during the Great Wall's construction

21,196.18km

Full length of the Great Wall

Equivalent to five times the width of the US

100 million tons

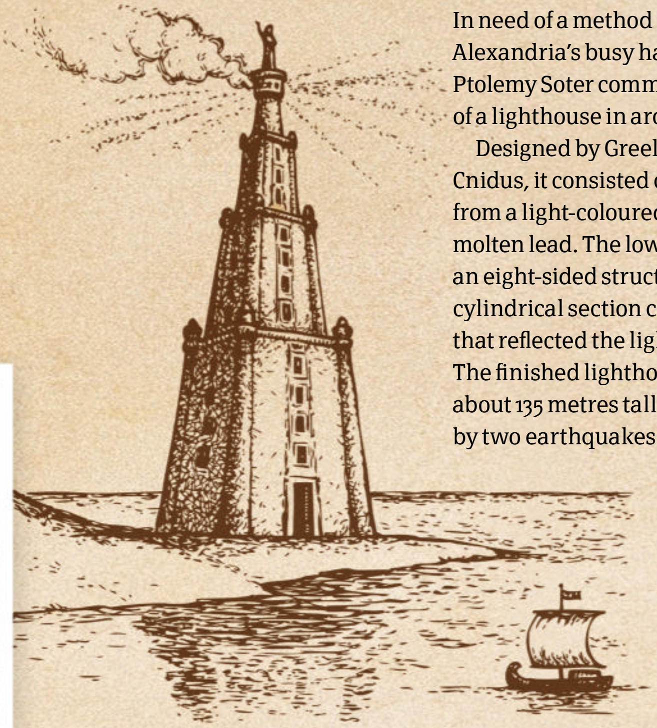
of brick, stone and mud were used to build it

14 metres

The tallest section is equivalent to the height of three buses

Pharos of Alexandria

The design and destruction of the world's first and most famous lighthouse



In need of a method for guiding trade ships into Alexandria's busy harbour, the Egyptian ruler Ptolemy Soter commissioned the construction of a lighthouse in around 280 BCE.

Designed by Greek architect Sostratus of Cnidus, it consisted of three levels, each built from a light-coloured stone and reinforced with molten lead. The lower square level supported an eight-sided structure, on top of which sat a cylindrical section containing a curved mirror that reflected the light from a fire into a beam. The finished lighthouse is thought to have been about 135 metres tall, but was reduced to rubble by two earthquakes in the 14th century.

The Pharos took 12 years and a considerable amount of slave labour to construct

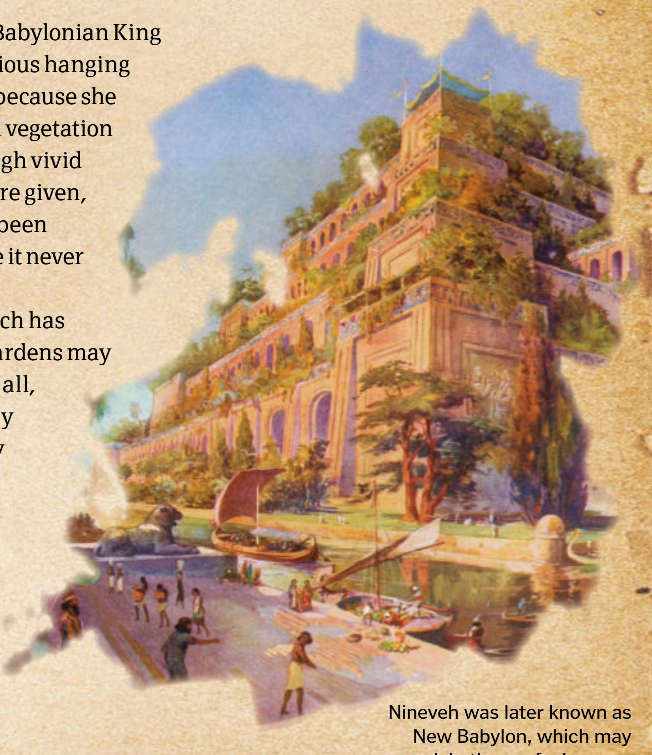
The Hanging Gardens of Babylon

A towering green oasis with a somewhat misleading name

According to ancient sources, Babylonian King Nebuchadnezzar II built a luscious hanging garden for his wife in 600 BCE because she was homesick for the beautiful vegetation of her native Media. But although vivid descriptions of the gardens were given, no physical evidence has ever been found, leading many to believe it never actually existed.

However, a more recent search has discovered that the hanging gardens may not have been in Babylon after all, but were instead built a century earlier in the city of Nineveh by King Sennacherib.

It is thought they were planted on a series of terraces and an Archimedes' screw device was used to douse them with 300 tons of water every day.



Nineveh was later known as New Babylon, which may explain the confusion over the garden's exact location

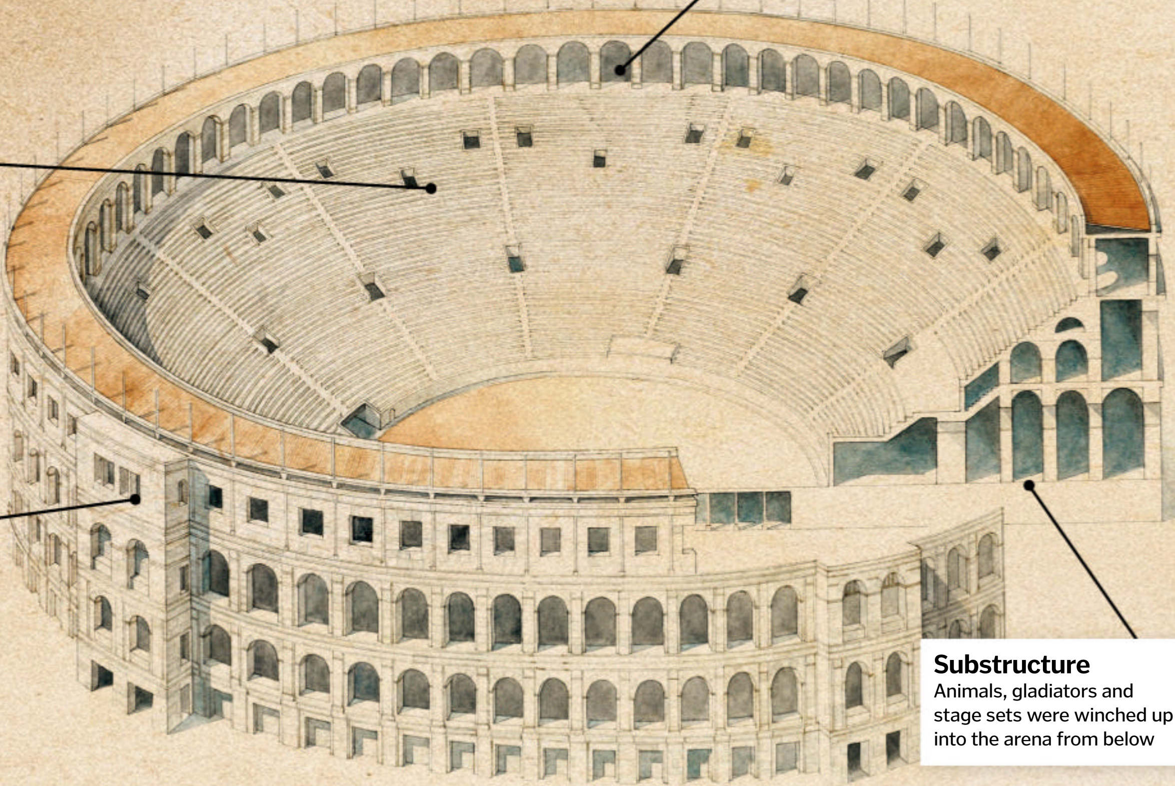
"The hanging gardens may not have been in Babylon after all"

© Thinkstock; Alamy

The Colosseum

Ingenious inventions and designs made the world's largest amphitheatre possible

In 80 BCE, after less than ten years of construction, Rome's enormous entertainment venue was completed. A pioneering feat of engineering, the Colosseum would go on to host bloody gladiator battles, re-enactments and executions for four centuries. The innovative four-tiered design of multiple vaulted arches provided the structure with plenty of support without adding excess weight and enabled more than 100,000 slaves to build it in simple, standardised parts. The recent invention of concrete also added strength to the Colosseum, helping it hold crowds of more than 50,000 people at a time.



Awnings
Wooden masts supported awnings that shaded the audience from the Sun

Seating
The tiered seating and elliptical design ensured everyone had a good view

Crowd control
Almost 80 separate arched entrances allowed the crowd to enter and exit with ease

Substructure
Animals, gladiators and stage sets were winched up into the arena from below

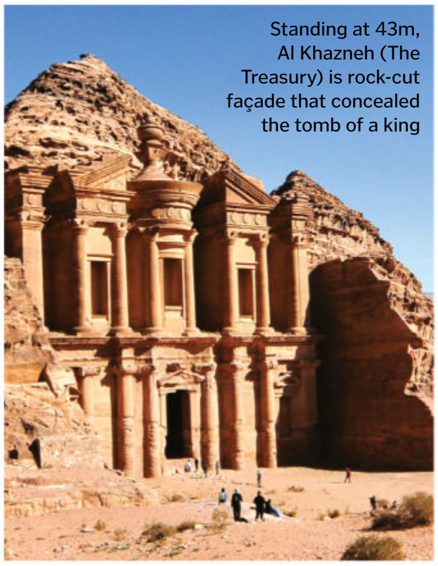
Petra

A unique 'Rose City' carved out of Jordan's desert rocks

Half-built and half-carved from the pink sandstone that inspired its colourful nickname, Petra was established as the capital of the Nabataean Kingdom in 400 BCE. As a busy trading hub, the historic city was once home to around 20,000 people, but getting access to water was difficult in the middle of the desert.

The Nabataeans solved this problem by constructing an elaborate water management system featuring cisterns, reservoirs and dams that conserved seasonal rains.

They chiselled their buildings out of the cliffs by carving steps into the surrounding rock, providing them with safe ledges to work from, and ensured important monuments aligned with the sunrise on winter solstice.



Standing at 43m, Al Khazneh (The Treasury) is rock-cut façade that concealed the tomb of a king

Banaue Rice Terraces

A giant staircase of rice fields built by hand

More than 2,000 years ago, the indigenous people of Ifugao in the Philippines came up with an ingenious method for farming on steep terrain.
With no tools available, they carved a series of terraces out of the mountain, bordering them with walls of mud and stone. They then harvested water from the forests on top of the mountain, flooding the individual fields so that rice could grow. This method of farming and sustaining the terraces has since been passed down through the generations and is still practised today.

The rice terraces can be found in the Cordillera Mountains

Machu Picchu

The amazing engineering found in the Inca's lost city

Meaning 'old mountain' in the native Quechua language, Machu Picchu stands 2,430 metres above sea level in the Peruvian Andes.

Only recently rediscovered in 1911, the city was built by the Inca people in the 15th century and then abandoned 100 years later when their empire was conquered by the Spanish. As the Inca had no written language, there are no records indicating the purpose of the site, but many archaeologists believe it was a royal estate used by leaders.

Set on the steep mountain slopes, the 200 buildings were constructed using a dry-stone technique without mortar. Blocks of granite were precisely cut and tightly slotted together like a jigsaw, leaving cracks so small even a knife could not penetrate them.

> *"Machu Picchu stands 2,430 metres above sea level in the Peruvian Andes"*

Machu Picchu features palaces, plazas, temples, homes and an irrigation system

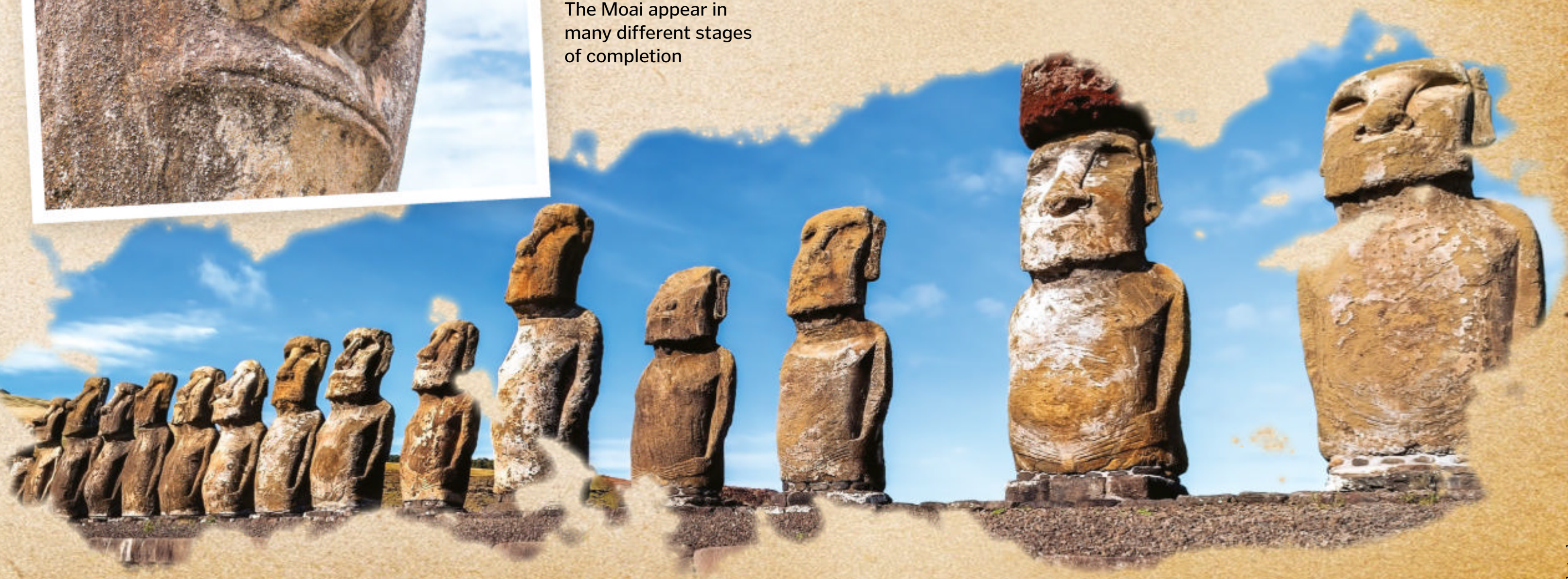
Easter Island statues

The giant stone heads that required a lot of heavy lifting

In the middle of the Pacific Ocean, almost 900 enormous statues called Moai can be found surrounding the remote Chilean island of Rapa Nui, the original name given to Easter Island by its Polynesian settlers.

The statues were made by the Polynesians sometime between the 12th century and the 17th century, and are thought to represent their dead ancestors.

Despite being carved out of a light, porous rock called tuff, which is formed by compacted volcanic ash, they each weigh several tons, and exactly how they were moved into position still remains a mystery.



The Moai appear in many different stages of completion

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Stonehenge

A prehistoric monument helping us to uncover the secrets of the past

In the Wiltshire countryside of England stands one of the most iconic and oldest human-made landmarks in the world.

Built over thousands of years, Stonehenge is the only surviving stone circle of its kind and has become a site of incredible archaeological importance. Although it has revealed a lot about certain practices of the past, the structure is still shrouded in mystery, mainly because we still can't be sure what it was built for.

The most popular theory is that it was a prehistoric temple, as the stones are precisely aligned with the movements of the Sun across the sky, which has special religious significance. What we do know is that its construction began in 3100 BCE, when a large circular ditch was dug using tools made from antlers. Around this time, the site was used for burials; in fact it's the largest late Neolithic cemetery in the UK.

In 2500 BCE, the stones were erected, having been worked into shape and smoothed using sarsen and flint hammerstones, and a few hundred years later were rearranged into their final position. Over the years many of the stones have toppled or been removed, leaving Stonehenge in its current state.

Superhenge

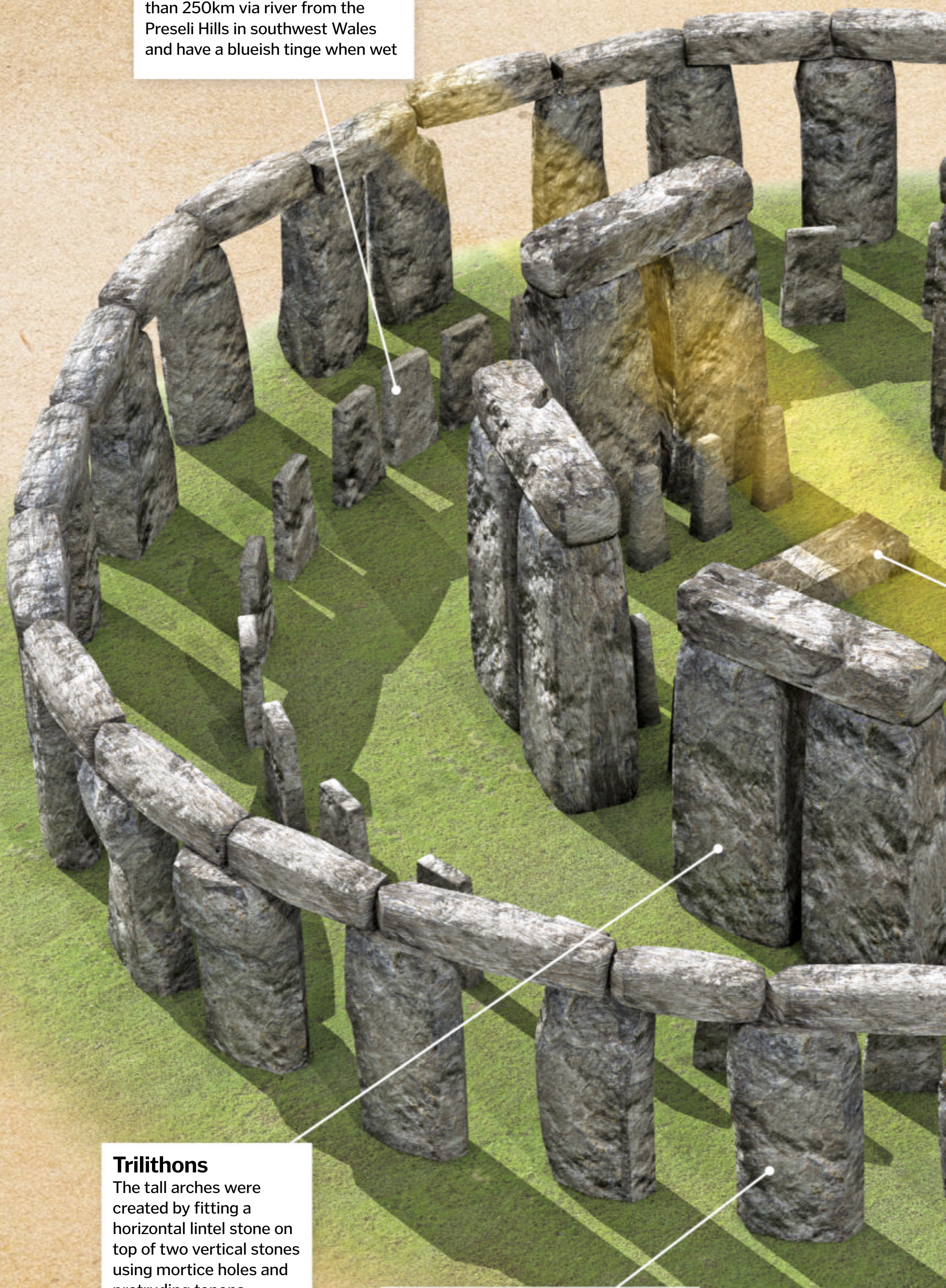
In 2015, scientists found what they thought was another stone monument, five times the size of Stonehenge, buried less than three kilometres away from the iconic landmark. Dubbed a 'superhenge', it was detected using ground-penetrating radar and believed to feature more than 100 stone monoliths.

However, when a dig was conducted, archaeologists instead found a series of deep pits that once held large wooden poles. The site was originally home to the people who built Stonehenge and the poles were erected when they left, perhaps as a memorial. However, they were later removed, and the pits were filled with chalk and covered over with a dirt bank.

The superhenge monument featured wooden poles, not large stones as previously thought

The Henge completed

Discover how Stonehenge might have looked in 2200 BCE

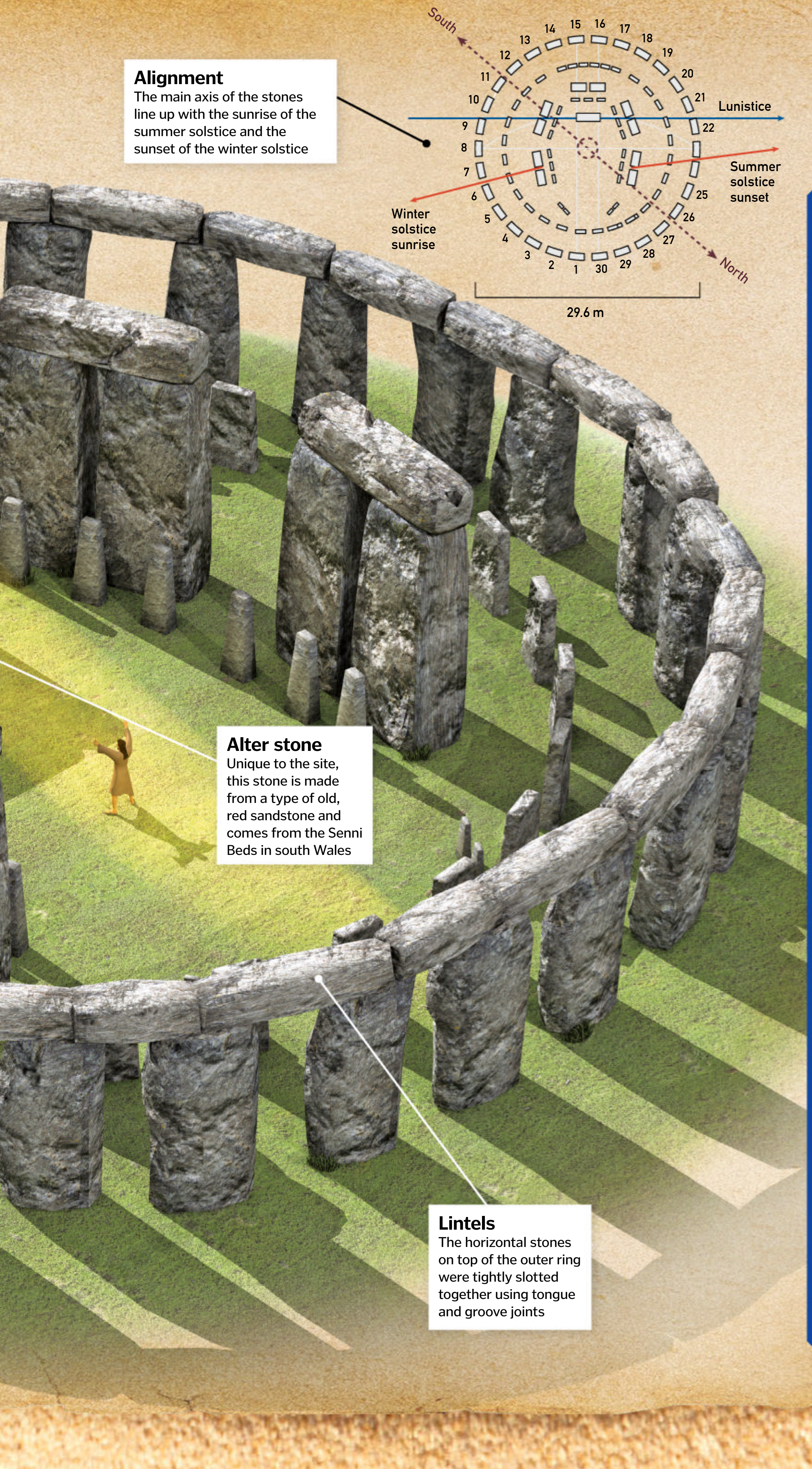


Bluestone
The smaller stones travelled more than 250km via river from the Preseli Hills in southwest Wales and have a blueish tinge when wet

Trilithons
The tall arches were created by fitting a horizontal lintel stone on top of two vertical stones using mortice holes and protruding tenons

Sarsen stone
These large sandstones came from the Marlborough Downs 32 kilometres away and on average weigh 25 tons each

DID YOU KNOW? *In 1915, Cecil Chubb went to an auction to buy chairs but instead bought Stonehenge for £6,600*


South
13
14
15
16
17
18
12
19
11
20
10
21
Lunistice
9
22
8
7
Summer solstice sunset
6
25
Winter solstice sunrise
5
26
4
27
3
28
2
1
30
29
North
29.6 m

Alignment
The main axis of the stones line up with the sunrise of the summer solstice and the sunset of the winter solstice

Alter stone
Unique to the site, this stone is made from a type of old, red sandstone and comes from the Senni Beds in south Wales

Lintels
The horizontal stones on top of the outer ring were tightly slotted together using tongue and groove joints

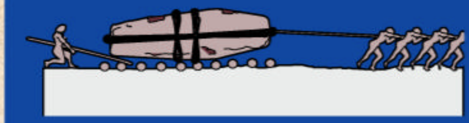
> *"Stonehenge is the only surviving stone circle of its kind"*

Assembling Stonehenge

How might the structure have been put in place with primitive tools?

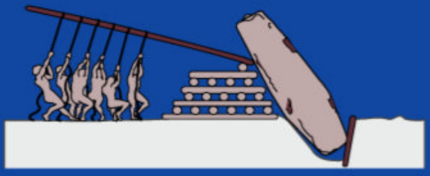
Transportation

The stones were dragged to the site on rollers and sledges, and some even came on rafts down the River Avon.



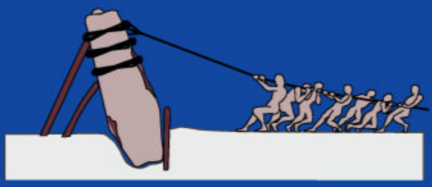
Positioning

The stones were placed in large holes with sloping sides and lined with wooden stakes at the back.



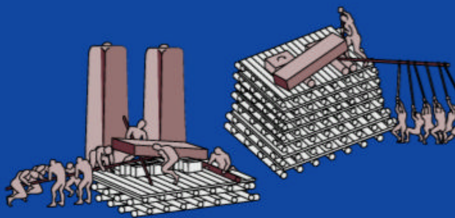
Raising the stones

Ropes, a wooden A-frame and sheer manpower were used to pull the stones upright, then the hole was packed with rubble.



Placing the lintels

Timber platforms were used to lift the horizontal lintels into position before they were placed on top of the upright stones.



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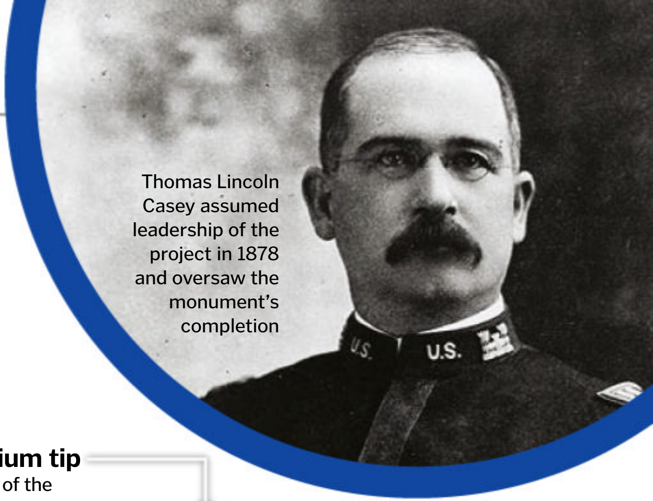
The Washington Monument

Inside the US capital's iconic marble obelisk that commemorates the achievements of the nation's first president

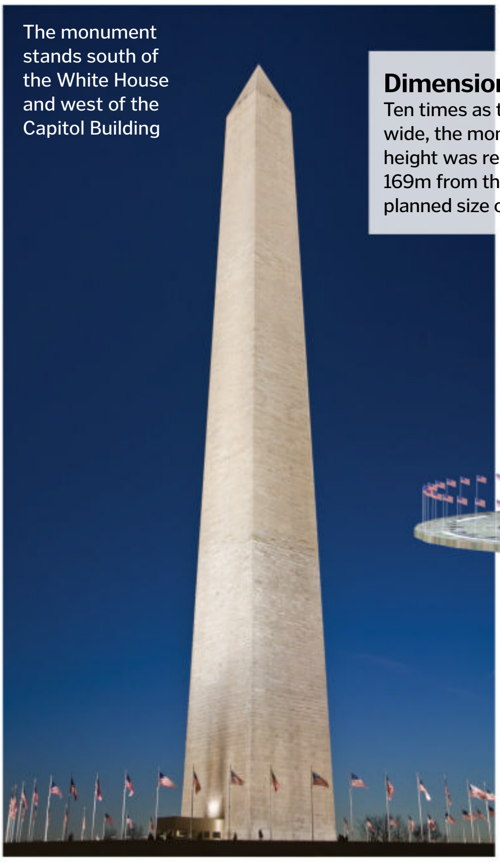
Standing tall above the US' capital city, the Washington Monument is a constant reminder of the legacy of founding father George Washington. As the first president of the United States, he is one of the most important figures in the nation's history.

The 169-metre-high monument was designed by Robert Mills in the shape of an Ancient Egyptian obelisk. It started out as a private project that was financed by the Washington National Monument Society, with Mills contributing the chosen design. A crowd of around 20,000 Americans gathered to watch as the first cornerstone was laid on 4 July 1848.

However, the project soon ran into issues. In 1854, the society was declared bankrupt, and a year later Mills died. Construction was halted throughout the US Civil War and was only restarted in 1876. The US Congress took control over construction and things ran much more smoothly. The monument was finally completed in 1884 and eventually opened to the public four years later.



Thomas Lincoln Casey assumed leadership of the project in 1878 and oversaw the monument's completion

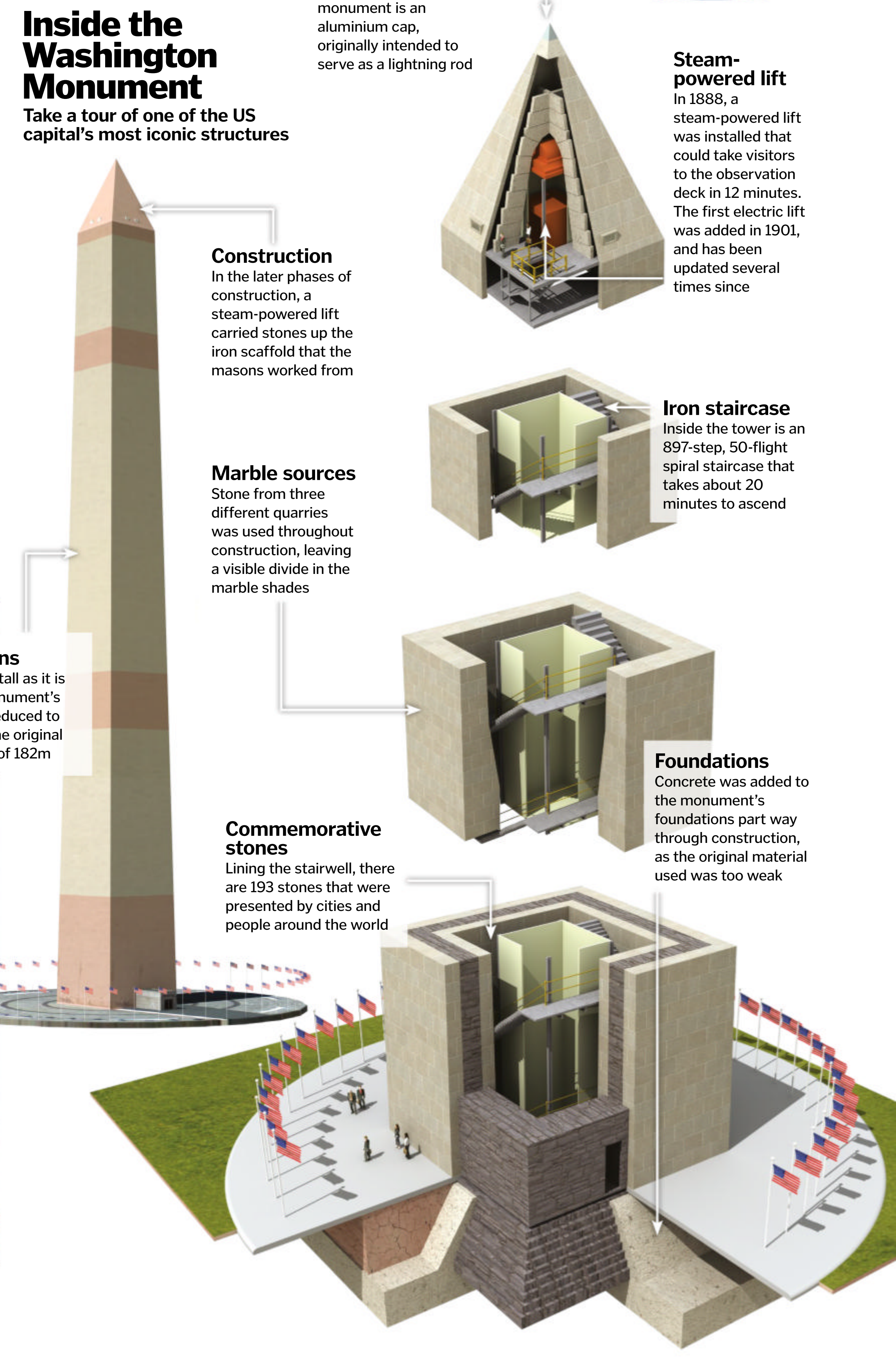


The monument stands south of the White House and west of the Capitol Building

© Illustration by Adrian Mann; WIKI

Inside the Washington Monument

Take a tour of one of the US capital's most iconic structures



Aluminium tip
At the top of the monument is an aluminium cap, originally intended to serve as a lightning rod

Steam-powered lift
In 1888, a steam-powered lift was installed that could take visitors to the observation deck in 12 minutes. The first electric lift was added in 1901, and has been updated several times since

Construction
In the later phases of construction, a steam-powered lift carried stones up the iron scaffold that the masons worked from

Iron staircase
Inside the tower is an 897-step, 50-flight spiral staircase that takes about 20 minutes to ascend

Marble sources
Stone from three different quarries was used throughout construction, leaving a visible divide in the marble shades

Dimensions
Ten times as tall as it is wide, the monument's height was reduced to 169m from the original planned size of 182m

Foundations
Concrete was added to the monument's foundations part way through construction, as the original material used was too weak

Commemorative stones
Lining the stairwell, there are 193 stones that were presented by cities and people around the world

DID YOU KNOW? *Windmills are so popular in the Netherlands that the country celebrates a National Windmill Day*

Windmills

Find out how these towers have helped harness wind power throughout history

It is thought that the windmill was invented around 1,500 years ago. Historians are still unsure exactly where the first one was constructed, but it is believed that it was either in ancient China or ancient Persia.

The first windmill mechanisms used millstones powered by sails that rotated a drive shaft to pump water or mill cereal. They became an integral part of ancient agriculture and were also used in sawmills and to help with irrigation and drainage.

The first windmills turned on a vertical axis. Later versions revolved horizontally, which was found to be a more efficient process. Tail fans were also added to later models to automatically move the sails in the direction the wind was blowing.

To remedy variable wind speeds, modern windmills utilise overspeed controls to turn the mechanism away from the wind if the gusts are too powerful for the sails to handle. Before the invention of windmills, grinding corn, pumping water and cutting lumber was done by hand. Windmills sped up and increased the efficiency of the process significantly, having a dramatic impact on the world's agriculture and economy.

Inside a thatched smock mill

How a windmill uses wind power to mill grain

1 Revolving cap

The cap of the mill rotates to face whichever way the wind is blowing, increasing rotation speed

2 Sails

The lattice sails move anti-clockwise, turning the mechanism inside in a clockwise direction

3 Brake wheel

The sails catch the wind and turn the horizontal wind shaft, which in turn revolves the largest cog, the drive gear

4 Dual millstones

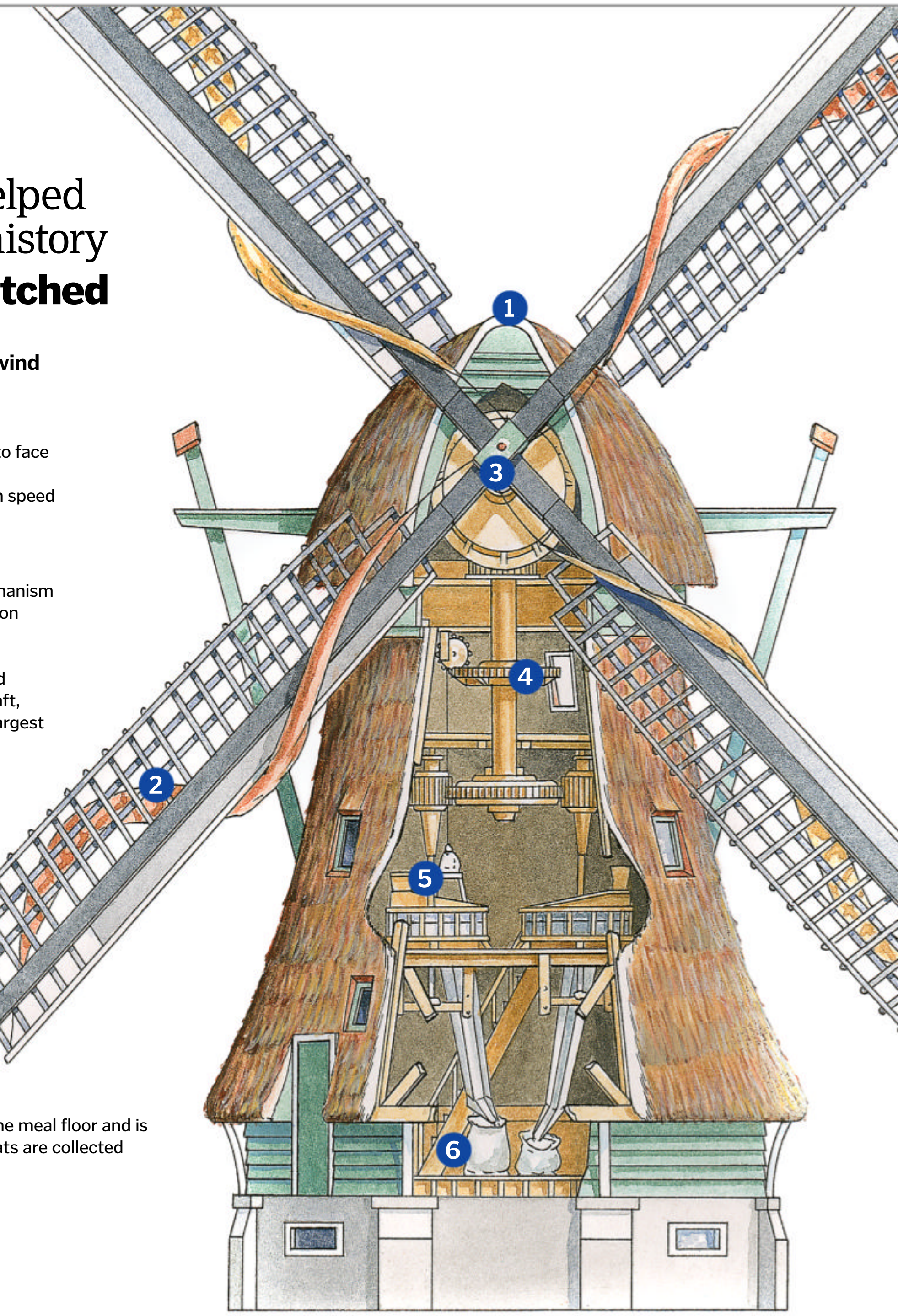
The movement of the drive gear turns a vertical shaft that powers a millstone

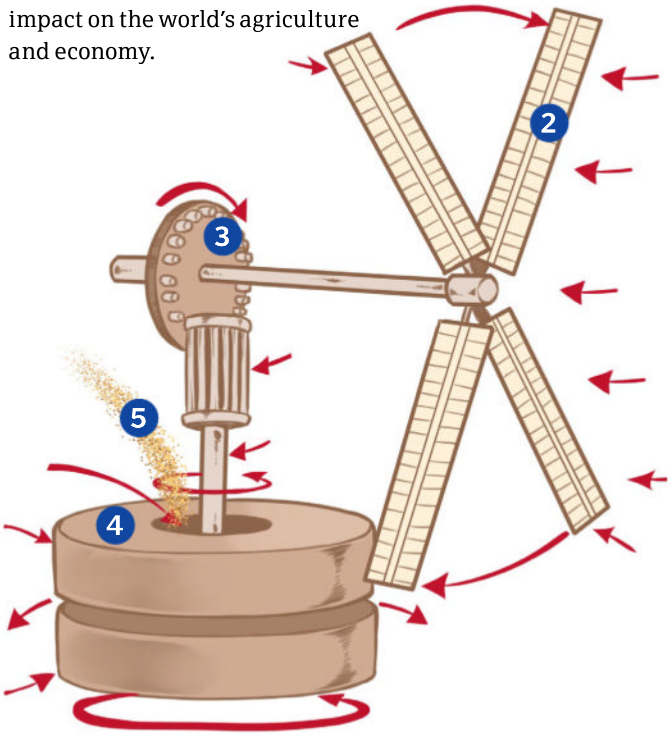
5 Feeding the grain

The grain is fed into the two millstones by a hopper. One millstone is still while the other rotates

6 Grain to flour

The bottom floor is called the meal floor and is where the flour, barley or oats are collected





Why did windmills fall out of use?

The use of windmills has declined in the modern world. This is primarily down to the introduction of steam power in the Industrial Revolution. This reduction only became even greater than before when electricity came into common use. Today, windmills are mainly listed as heritage sites or have fallen into disrepair. Rather than grinding grain, today's windmills take the form of wind turbines and are one of the world's leading renewable energy sources. Moreover, simple wind pumps have been around since ancient times and are still commonly used both for draining wetlands and obtaining groundwater in areas short on drinking water.

© Illustration by Rebekka Hearl; Thinkstock

The history of Central Park

How did such a huge area of New York City become a green space?

If you look at the huge, sprawling space in New York that is occupied by Central Park, you probably won't realise quite how much it has changed since it was first created. The land, acquired by the City of New York in 1853, was over 700 acres of mostly barren swampland.

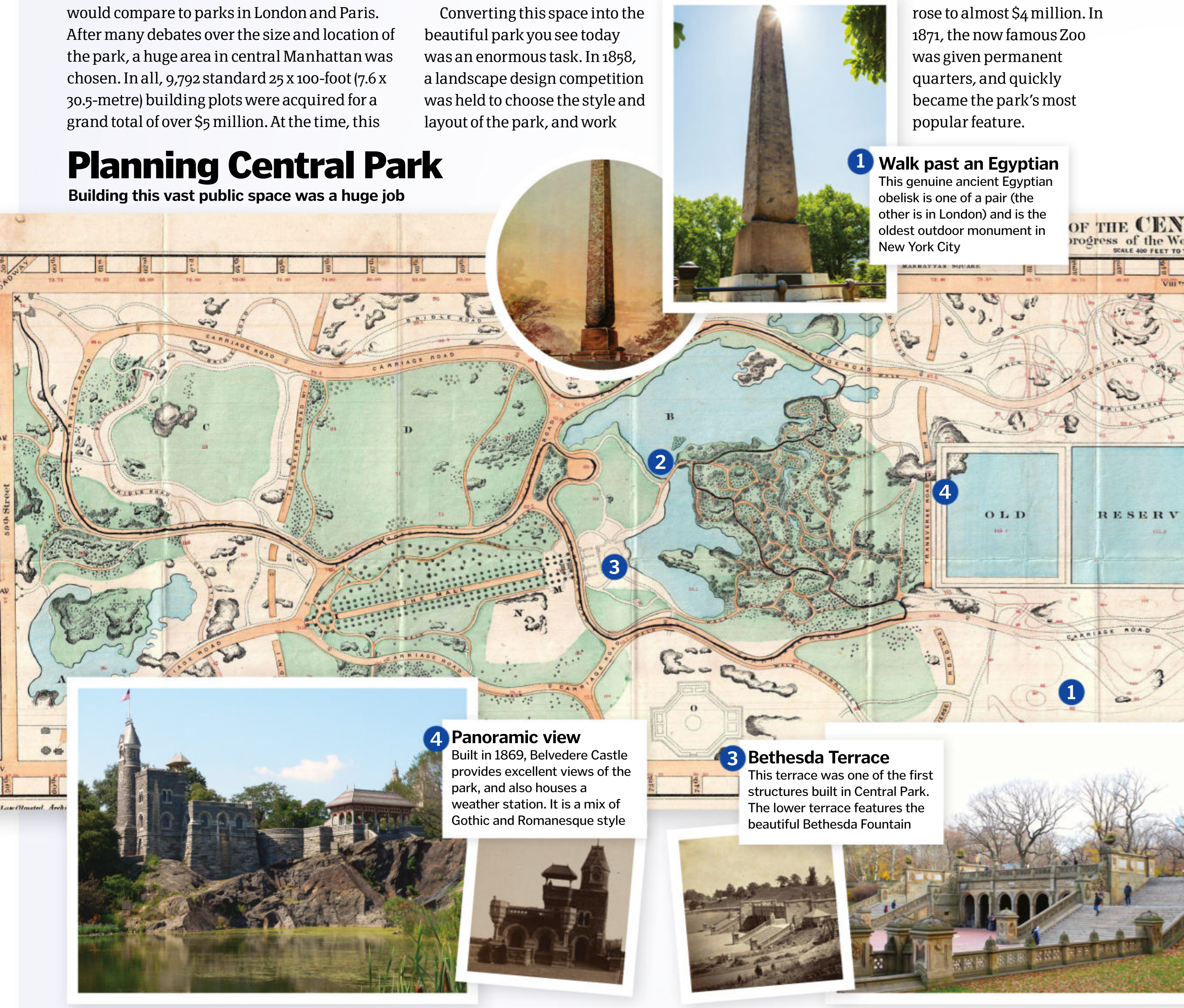
The story of Central Park began in the 1840s, when wealthy merchants and landowners urged the state to consider a public ground that would compare to parks in London and Paris. After many debates over the size and location of the park, a huge area in central Manhattan was chosen. In all, 9,792 standard 25 x 100-foot (7.6 x 30.5-metre) building plots were acquired for a grand total of over $5 million. At the time, this area was distant from the built-up area of the city, which was mainly in south Manhattan. The land chosen was uneven terrain, with rocky outcrops and swamps dotted around, making it undesirable for building. However, that didn't mean that there was nobody living there; in fact, around 1,600 poor residents were displaced by the project, including a stable African-American settlement in Seneca Village.

Converting this space into the beautiful park you see today was an enormous task. In 1858, a landscape design competition was held to choose the style and layout of the park, and work began soon after. It's estimated that 20,000 workers were involved in reshaping the land, and 260 tons of gunpowder was used to blast through the rock on site. Over 270,000 trees and shrubs were planted in the park, and a new reservoir was constructed. In the winter of 1859 the first part of the park opened to the public.

Construction continued for many years, and the cost of building the park rose to almost $4 million. In 1871, the now famous Zoo was given permanent quarters, and quickly became the park's most popular feature.

Planning Central Park

Building this vast public space was a huge job



1 Walk past an Egyptian
This genuine ancient Egyptian obelisk is one of a pair (the other is in London) and is the oldest outdoor monument in New York City

4 Panoramic view
Built in 1869, Belvedere Castle provides excellent views of the park, and also houses a weather station. It is a mix of Gothic and Romanesque style

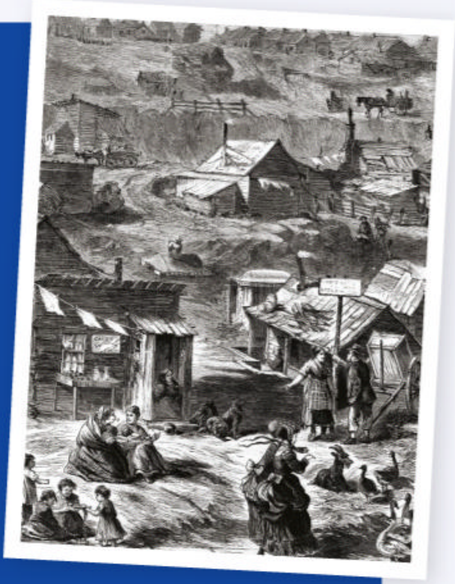
3 Bethesda Terrace
This terrace was one of the first structures built in Central Park. The lower terrace features the beautiful Bethesda Fountain

The park stretches from 59th Street all the way to 110th Street

The history of Seneca Village

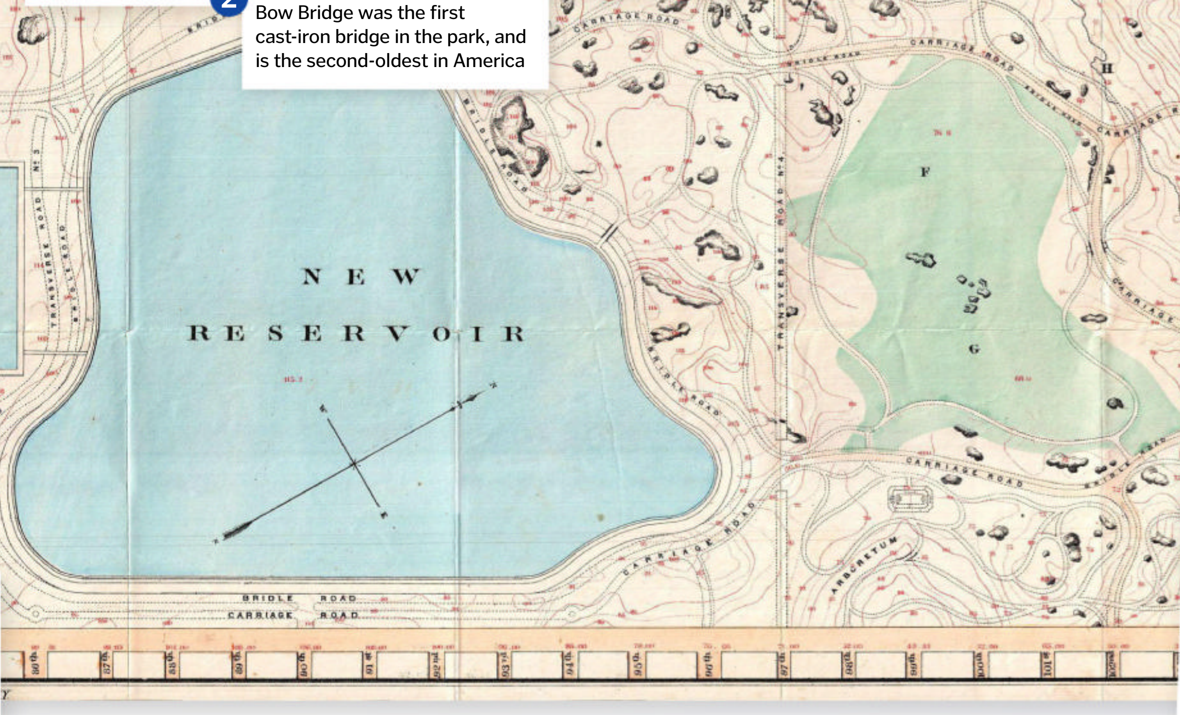
Seneca Village is an area within Central Park that looks like any other, but there is a lot of history hidden in the land. Nearly 200 years ago, in 1825, Andrew Williams and Epiphany Davis became the first African-Americans to purchase land in Seneca Village. Within four years, nine substantial houses had been built in the area, which was near the Hudson River (for fishing) and a natural spring.

By 1855 a census indicated that Seneca Village was home to around 250 people in 70 houses. However, when the plans for Central Park were made, the New York State legislature used a rule called 'eminent domain' to take this private land for public use, and compensate the owners in return. The community was forced to leave and the houses were demolished to build the park. Modern excavations in the area are now uncovering artefacts and stone foundations that tell us more about how the community lived.

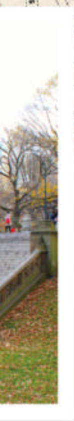

Seneca Village was home to African-Americans and European immigrants

> *"Creating the beautiful park you see today was an enormous task"*

2 Over the water
Bow Bridge was the first cast-iron bridge in the park, and is the second-oldest in America



Umpire Rock is more commonly known as Rat Rock because of the rats that used to swarm there at night



Five Central Park facts

Real history

Umpire Rock is one of several points where the bedrock of New York City is exposed. The rock was formed hundreds of millions of years ago during the Paleozoic era.

Sheep Meadow

The iconic Sheep Meadow really did use to be home to sheep. They were kept at the Tavern on the Green, and were let out to graze twice daily.

No racing!

The curved roads within the park were designed to stop people racing their carts and injuring people. Now people race their bikes along the paths instead!

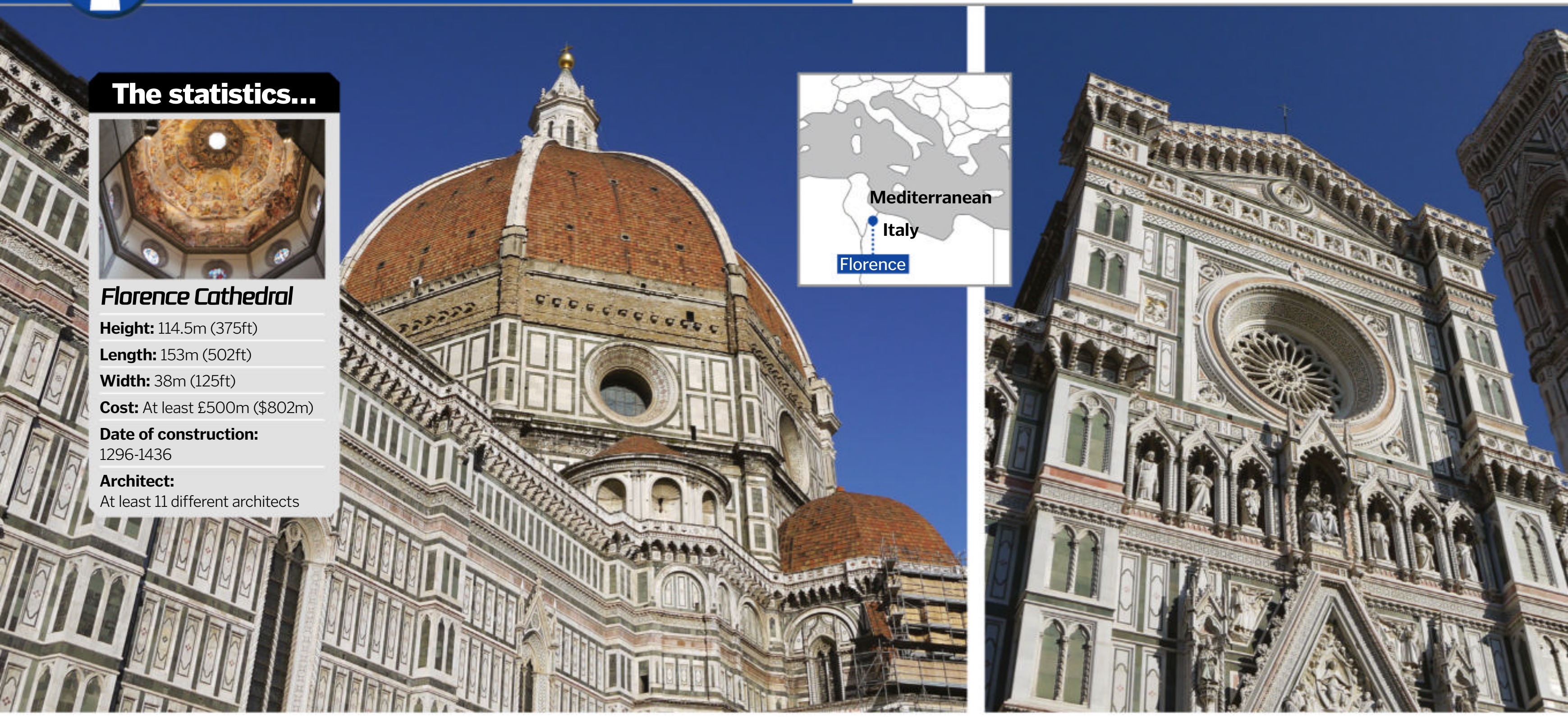
No picnics!

Strict rules in the first decade of the park's existence meant that group picnics were prohibited within the park, which discouraged a number of less wealthy families from visiting.

No ball games!

When the park was first completed, schoolboys were only allowed to play ball games on the lawns if they had a note signed by their principal.

© Thinkstock; Alamy; WIKI



The statistics...

Florence Cathedral

Height: 114.5m (375ft)
Length: 153m (502ft)
Width: 38m (125ft)
Cost: At least £500m ($802m)
Date of construction: 1296-1436
Architect: At least 11 different architects

Florence Cathedral

Crowned with the largest masonry dome in the world, Florence Duomo is a Renaissance masterpiece

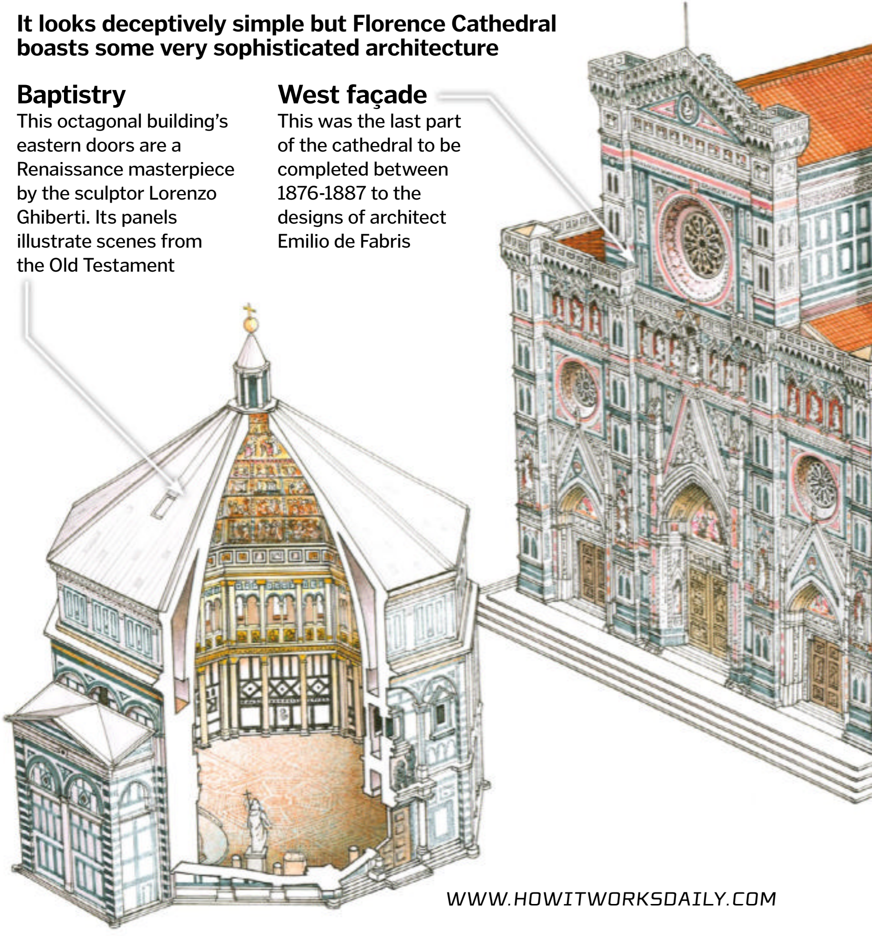
Popularly called the Duomo, Florence Cathedral's name is derived from the Latin 'domus dei' – the House of God – and is dedicated to the Virgin Mary Santa Maria del Fiore (St Mary of the Flower). The present building was started in 1296 and is the third cathedral to stand on the site. Taking 140 years to build, the original plan was only changed once during construction when the eastern half of the cathedral was massively expanded to allow for the now iconic dome. Work on this extraordinary structure began in 1420 and was completed in just 16 years. Higher and wider than any previously built, the octagonal dome was constructed without using a temporary wooden supporting frame. Consisting of a double shell made of sandstone, marble and brick, the base of the dome is about 52 metres (171 feet) above the ground and has a staggering 44-metre (144-foot) diameter.

The cathedral's exterior walls are faced in alternate vertical and horizontal bands of coloured marble – white from Carrara, green from Prato and red from Siena. Despite the many architects to work on it the building retains a remarkable architectural and aesthetic cohesion. The interior is sparsely decorated, but contains a number of major Renaissance artworks and 44 stained-glass windows – in fact, the largest expanse of glass installed during 14th and 15th century Italy.

Above the main door is the basilica's one-handed liturgical clock, which shows all 24 hours. Erected in 1443, it is still working today. The largest cathedral in Europe when it was built, it has become symbolic of Florence and its dome is instantly recognised around the globe. Such is the Duomo's cultural importance that the cathedral complex was designated a UNESCO World Heritage site in 1982.

A tour of the basilica

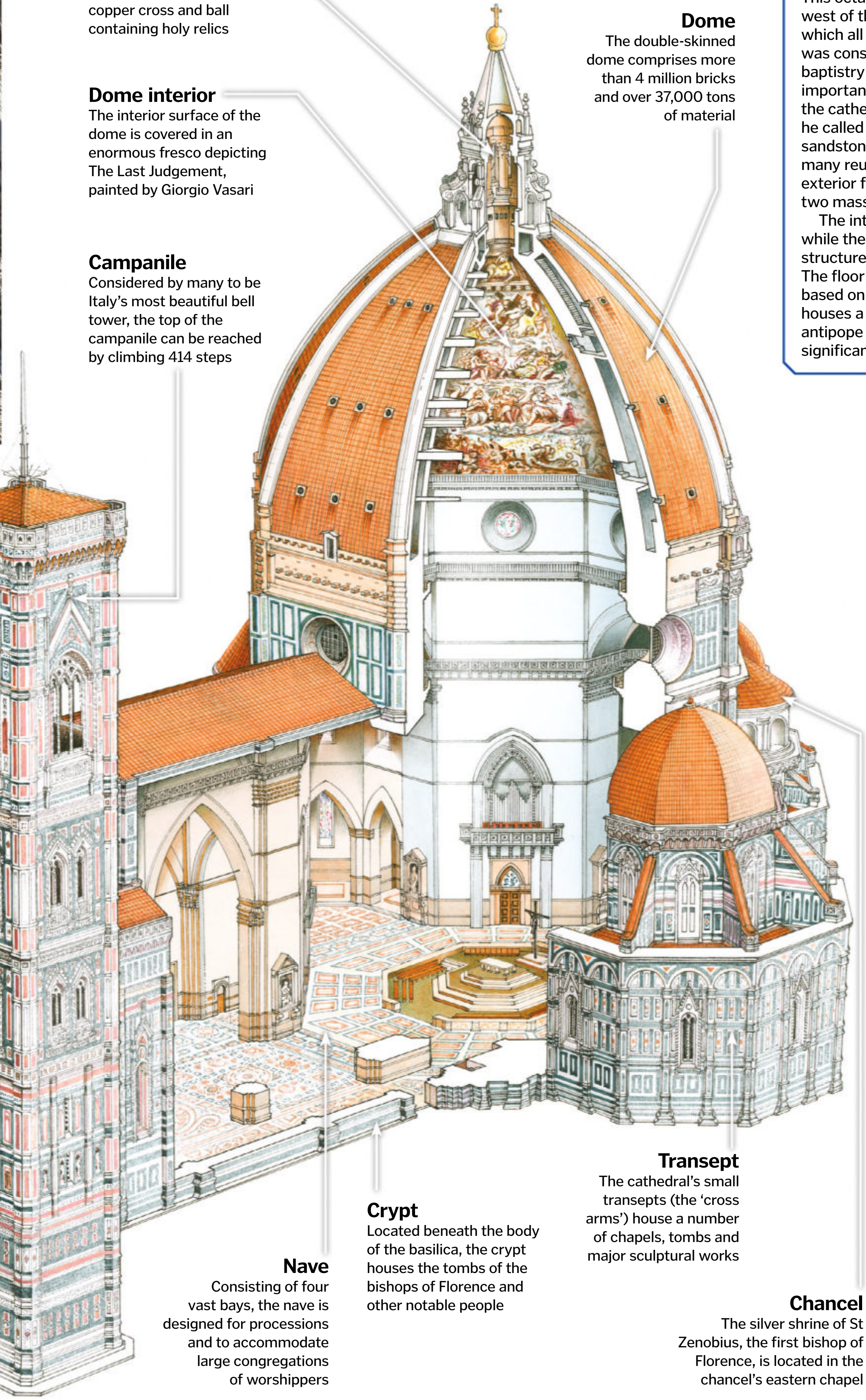
It looks deceptively simple but Florence Cathedral boasts some very sophisticated architecture



Baptistry
This octagonal building's eastern doors are a Renaissance masterpiece by the sculptor Lorenzo Ghiberti. Its panels illustrate scenes from the Old Testament

West façade
This was the last part of the cathedral to be completed between 1876-1887 to the designs of architect Emilio de Fabris

DID YOU KNOW? *The famous English mercenary, Sir John Hawkwood, was buried in Florence Cathedral in 1394*



Lantern
A stone lantern crowns the dome and is surmounted by a gilt-copper cross and ball containing holy relics

Dome interior
The interior surface of the dome is covered in an enormous fresco depicting The Last Judgement, painted by Giorgio Vasari

Campanile
Considered by many to be Italy's most beautiful bell tower, the top of the campanile can be reached by climbing 414 steps

Dome
The double-skinned dome comprises more than 4 million bricks and over 37,000 tons of material

Transept
The cathedral's small transepts (the 'cross arms') house a number of chapels, tombs and major sculptural works

Crypt
Located beneath the body of the basilica, the crypt houses the tombs of the bishops of Florence and other notable people

Nave
Consisting of four vast bays, the nave is designed for processions and to accommodate large congregations of worshippers

Chancel
The silver shrine of St Zenobius, the first bishop of Florence, is located in the chancel's eastern chapel

The Baptistry of St John

This octagonal building stands slightly to the west of the cathedral. Built to house the font in which all Christians in Florence were baptised, it was constructed between 1059 and 1128. The baptistry is famous for three sets of artistically important bronze doors. The eastern pair, facing the cathedral, so impressed Michelangelo that he called them the 'Gates of Paradise'. Made of sandstone and faced with marble incorporating many reused fragments of Roman buildings, the exterior features many sculptural groups and two massive porphyry columns.

The interior of the baptistry is clad in marble, while the inside of the dome which roofs the structure is inlaid with magnificent gold mosaics. The floor is covered in marble featuring a design based on the zodiac. Unusually, the baptistry also houses a number of tombs, including that of the antipope John XXIII which is considered a significant early-Renaissance sculptural work.

Giotto's campanile

The campanile, or bell tower, was designed by the celebrated painter Giotto di Bondone and it houses seven bells. Standing next to the cathedral, it is built from the same coloured marbles and so blends in well with its neighbour. The tower is square in plan with sides measuring 15 metres (47 feet) and it soars 87 metres (278 feet) high. Embraced by polygonal buttresses at its corners, it's divided into five separate levels – the upper three of which contain windows. Each of the three top levels is larger than the one below it in every dimension. These differences in size counter the effect of perspective so when viewed from below, the three top levels of the tower look equal in size. Although Giotto originally intended the campanile to be surmounted by a tall spire, after his death it was decided to build a large projecting terrace instead, which lends the tower a dramatic 'broken off' look.

© Thinkstock

How was the Sistine Chapel's ceiling painted?

Explore the tools and techniques behind Michelangelo's lofty Renaissance masterpiece

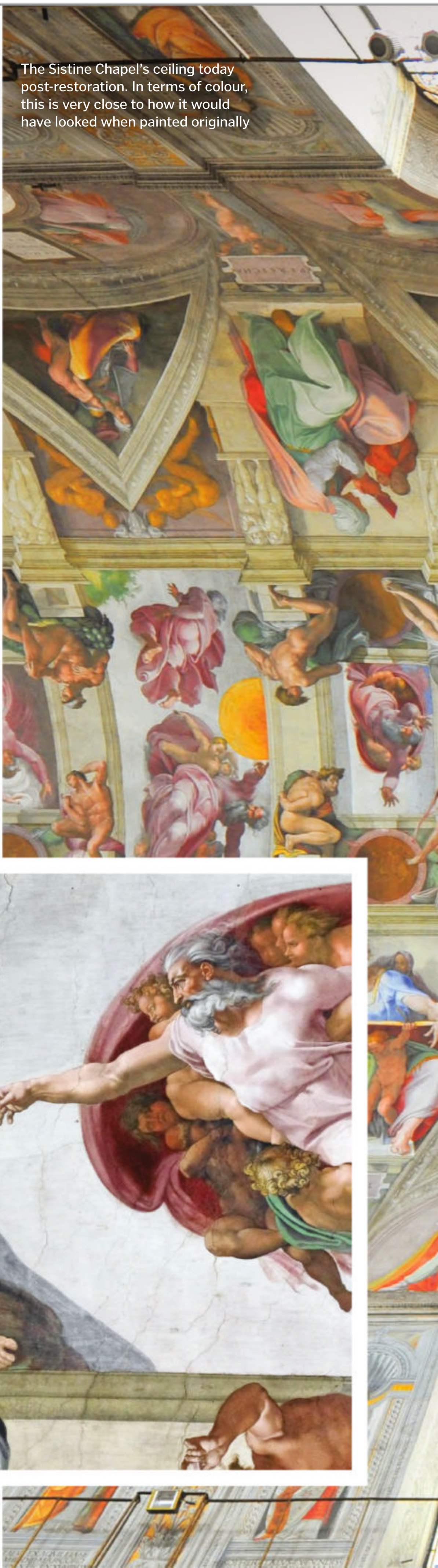
In painting the Sistine Chapel's ceiling in the early part of the 16th century, Michelangelo had to overcome a number of daunting hurdles. The first comes directly from the physical properties of the ceiling, as it is a barrel vault, which is a curved surface. To make it more difficult still, that barrel vault is intersected with smaller vaults positioned over the windows. As such there are no flat surfaces anywhere except around the windows, where the artist also painted a series of half-moon-shaped lunettes. As a result, even prior to picking up a paintbrush Michelangelo had to first work out how to create realistic portrayals of human figures in proper proportion and in motion on these wildly uneven surfaces. His ability to pull this off is testament to his immense artistic skill.

Another major challenge in painting the Sistine Chapel's ceiling was actually getting up there, as it is 20 metres above the floor. Fortunately, a conservation campaign that started in the Eighties revealed the method Michelangelo employed to reach such heights: he constructed a complex scaffold. The scaffold consisted of a truss bridge that spanned across the vault and ran on rails that were at a 90-degree angle to the walls. This permitted Michelangelo to access all areas of the ceiling as the scaffolding could be moved along the rails – it was only ever covering a quarter of the vault at any one time, as he needed ambient light from the windows to paint. Interestingly, the holes that were made to support this structure can still be seen in the walls to this day.

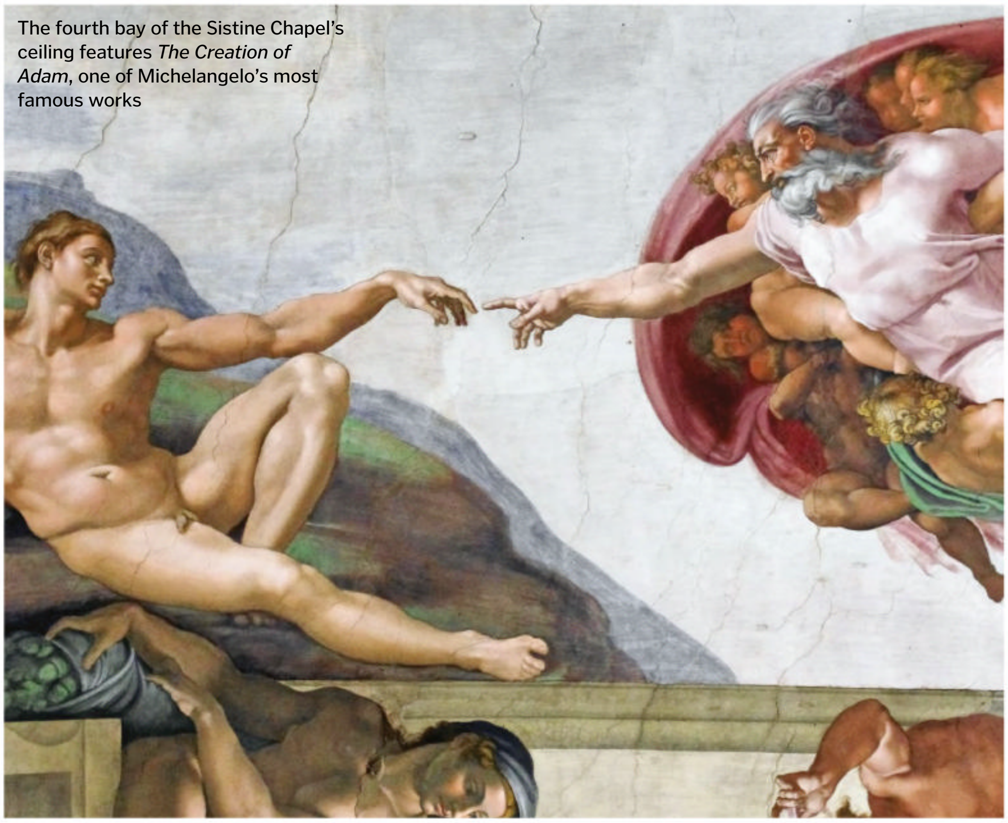
The third problem Michelangelo had to tackle was how to lay out the sketch lines for the entire ceiling. He did this by dividing the vault into various units by stretching chalked strings from one end of the chapel to the other (with help from assistants), before snapping them against the prepared plaster. In doing this, he laid out the linear structure of all the architecture, which is consistent throughout.

The last major obstacle that Michelangelo faced was the sheer scale of the project, which incredibly only took four years to complete. Painting the ceiling was a massive logistical undertaking and so he invited some of his friends from Florence to Rome to aid him.

As well as painting some of the recurring elements, such as columns and statues, these assistants helped him to build the scaffolding and mix/prepare the plaster, as well as lending a hand with the manufacture of paints, the trimming of paintbrushes and the sketching of full-sized drawings on paper for transferral onto the vault. This latter process involved the paper sketch being pressed against the ceiling, pricked with small holes around the outlines and then covered with black chalk dust to produce a dotted outline on the plaster.



The Sistine Chapel's ceiling today post-restoration. In terms of colour, this is very close to how it would have looked when painted originally



The fourth bay of the Sistine Chapel's ceiling features *The Creation of Adam*, one of Michelangelo's most famous works

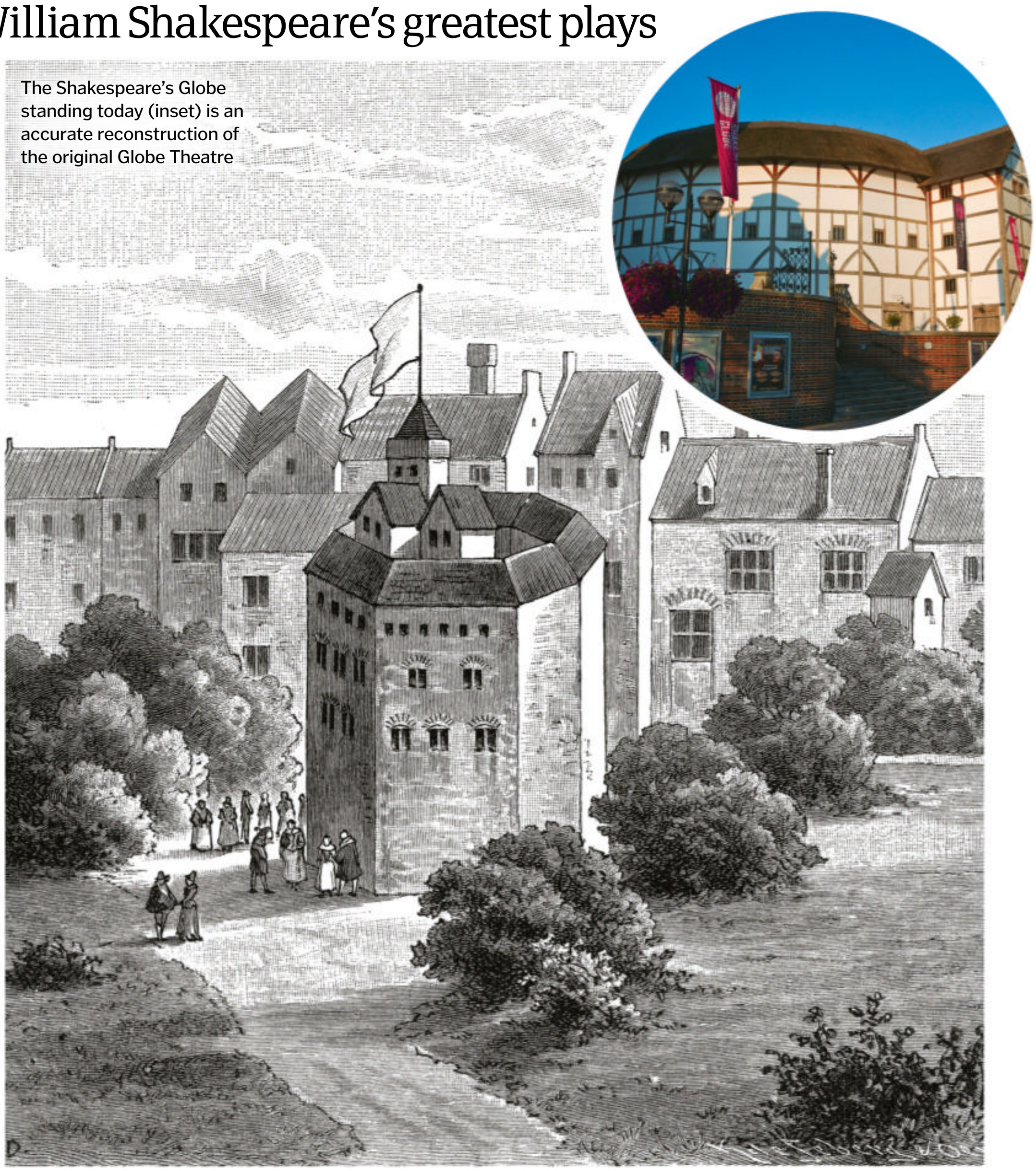
© Joe Angeles; Cambridge University Press/William Wallace

The Globe Theatre's story

The most famous and historic theatre in Britain – if not the world – the Globe was the original home to William Shakespeare's greatest plays

The Globe Theatre was an Elizabethan-era playhouse part-owned and made famous by the great playwright William Shakespeare. Built from the remains of an existing theatre in Shoreditch, London, made by English actor and theatre owner Richard Burbage and his brother Cuthbert, the Globe was constructed out of timber over just a few months in 1599. It was a very attractive and imposing theatre at its time. The playhouse became the home of the Lord Chamberlain's Men, a troupe of which Shakespeare and the Burbages were members. The group went on to perform many of the Bard's most famous plays there. Reportedly, the first performance was *Julius Caesar*, with subsequent famous plays such as *Richard II, Romeo And Juliet* and *A Winter's Tale* also shown there.

The Globe proved a great success, with its 3,000 capacity frequently tested to the limit, both in the cheap standing-only pit area as well as in the more prestigious tiered seating located around the inner walls. Unfortunately, however, on 29 June 1613 during a performance of *Henry VIII*, a theatrical cannon misfired and ignited the wooden beam and thatch roof, leading to the entire building burning down. Luckily, the success of the Globe's owners and its performances resulted in the theatre being rebuilt again in 1614, with the new playhouse continuing to host many acting troupes well after Shakespeare's death in 1616. In fact, it was not until 1642 that the theatre was closed down – a casualty of the English Civil War. Its legacy, however, is just as eternal as the plays written by the Bard himself.



The Shakespeare's Globe standing today (inset) is an accurate reconstruction of the original Globe Theatre

The Globe over time

Check out some of the main events in the theatre's history now

1599: Grand opening

The Globe Theatre is opened on Bankside, London.

1601: *Richard II* runs

Shakespeare's acting troupe, the Lord Chamberlain's Men, are commissioned to stage *Richard II*.

1608: Blackfriars bought

The Globe's co-owner, Richard Burbage, acquires the lease for the Blackfriars Theatre, which is then used for winter performances.

1614: Globe rebuilt

Following a disastrous fire that burned down the Globe, it is rebuilt a year later on the original foundations.

1997: Resurrection

An accurate reconstruction of the Globe is built near to the site of the original building. It stages Shakespeare's works and is a popular tourist attraction to this day.

1644: Globe destroyed

The theatre is razed to the ground again – this time by order of the Puritans. Landowner Sir Matthew Brend builds tenement houses on the site in its place.

1642: Plays suppressed

In the English Civil War, Parliament issues an ordinance that forbids all stage plays. The Globe is shut down.

1616: Mortal coil

William Shakespeare dies aged 52 in Stratford-upon-Avon, where he is buried in the Holy Trinity Church.

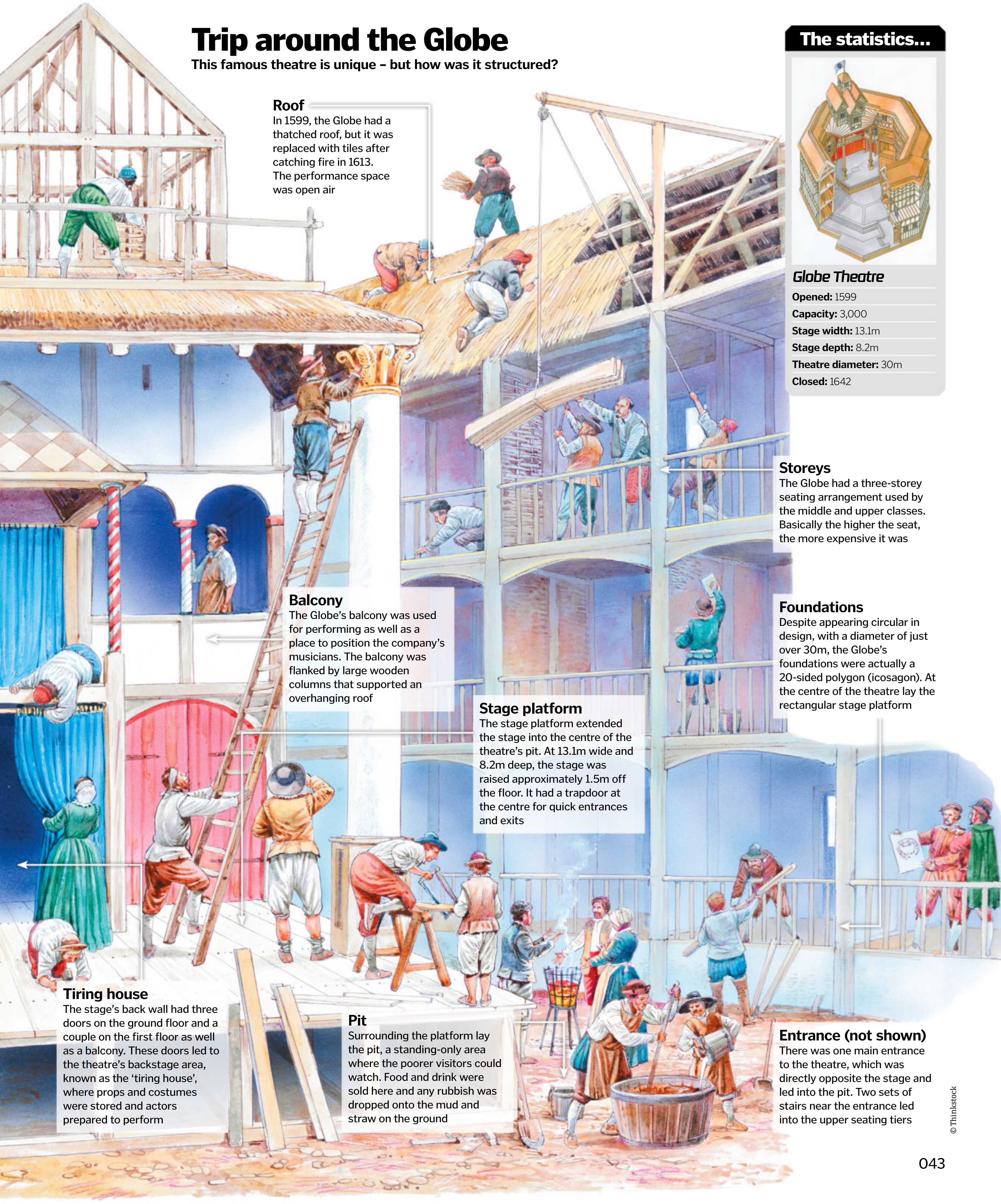
A modern-day Globe

Theatre fans today can visit the modern reconstruction of the Globe. It was nevertheless made to be historically accurate, consulting the plans, construction methods and materials of the 1599 original, albeit with modern safety standards in mind. Shakespeare's Globe is built from 100 per cent English oak, with components linked with mortise and tenon joints – both features shared by the original – and also has the only thatched roof permitted in all London since the Great Fire of 1666. The attention to historical detail even extends to the pit area, which remains standing only, albeit with a concrete surface rather than the earthen/straw mix of the 16th/17th century. A second Shakespearean play venue, the Blackfriars Theatre, has been reconstructed and opened as the Sam Wanamaker Playhouse in January 2014.

DID YOU KNOW? *The modern reconstruction of the Globe is located 230m (750ft) from the original site*

Trip around the Globe

This famous theatre is unique – but how was it structured?



Roof

In 1599, the Globe had a thatched roof, but it was replaced with tiles after catching fire in 1613. The performance space was open air

Balcony

The Globe's balcony was used for performing as well as a place to position the company's musicians. The balcony was flanked by large wooden columns that supported an overhanging roof

Storeys

The Globe had a three-storey seating arrangement used by the middle and upper classes. Basically the higher the seat, the more expensive it was

Foundations

Despite appearing circular in design, with a diameter of just over 30m, the Globe's foundations were actually a 20-sided polygon (icosagon). At the centre of the theatre lay the rectangular stage platform

Stage platform

The stage platform extended the stage into the centre of the theatre's pit. At 13.1m wide and 8.2m deep, the stage was raised approximately 1.5m off the floor. It had a trapdoor at the centre for quick entrances and exits

Tiring house

The stage's back wall had three doors on the ground floor and a couple on the first floor as well as a balcony. These doors led to the theatre's backstage area, known as the 'tiring house', where props and costumes were stored and actors prepared to perform

Pit

Surrounding the platform lay the pit, a standing-only area where the poorer visitors could watch. Food and drink were sold here and any rubbish was dropped onto the mud and straw on the ground

Entrance (not shown)

There was one main entrance to the theatre, which was directly opposite the stage and led into the pit. Two sets of stairs near the entrance led into the upper seating tiers

The statistics…

Globe Theatre

Opened: 1599

Capacity: 3,000

Stage width: 13.1m

Stage depth: 8.2m

Theatre diameter: 30m

Closed: 1642

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What went wrong at Chernobyl?

Learn how a runaway reaction led to a nuclear disaster…

On 25 April 1986, engineers at the nuclear plant at Chernobyl began a test that would lead to the worst nuclear disaster in history. The power plant, located around 130 kilometres north of Kiev, Ukraine, was completed in 1983. Three years later, engineers ran an experiment to see how long the turbines could continue producing energy in the event of a power cut.

The first fatal error made by the technicians that day was to turn off the crucial safety systems in the facility. They would have affected the experiment, which involved running the plant at low power, but this action prevented workers realising the dire situation they were soon to put themselves in.

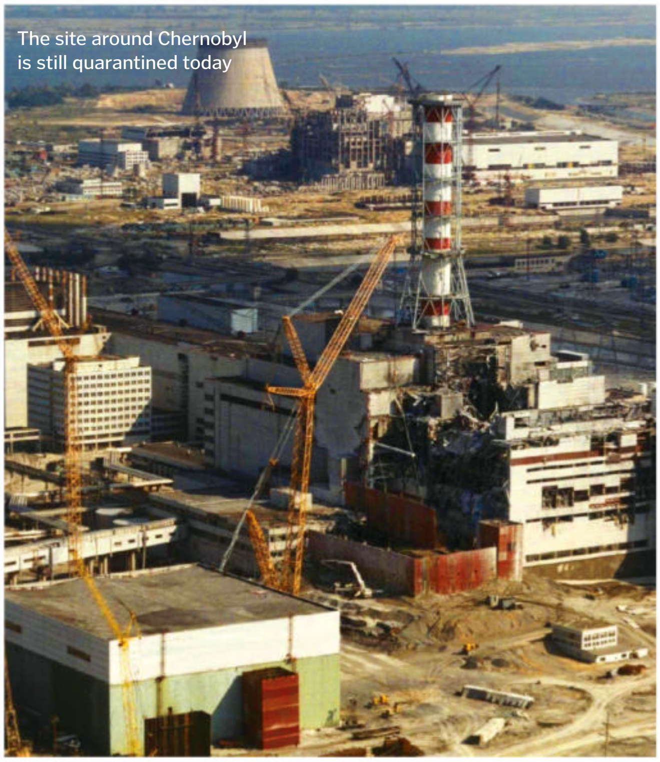
The process of creating nuclear fission is regulated by control rods, which, when inserted into the reactor core, absorb neutrons and slow production. The idea was to lower lots of these rods to reduce the power output and see what happened. Unfortunately, too many were lowered and the output dropped at too high a rate. Rods were then raised again to increase output, returning to about 12 per cent.

However, due to the rods being raised too far and too quickly, a dangerous power surge occurred and the reactor overheated; the water cooling system, unable to cope with the sudden demand, turned to steam.

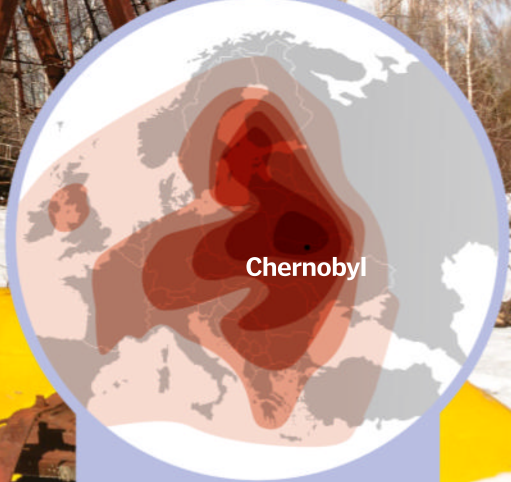
The emergency button was pressed and the rods began to lower but this led to even more rapid reactions in the core.

In the early hours of 26 April, the reactor's roof was blown off and radioactive material began to escape into the atmosphere.

The fire took nine days to extinguish and the radioactive material had far-reaching health and political consequences.



The site around Chernobyl is still quarantined today



Nuclear fallout

The explosion and meltdown was shocking enough, but worse was still to come in the form of radiation spread and health issues for much of Europe.

31 people died immediately after the event with 28 of those deaths a direct result of radiation poisoning inside and around the power plant site.

The worst of the fallout centred around Chernobyl, but increased levels of radiation were detected in areas as far away as the UK, Portugal and Sweden.

Thyroid cancer, caused by the inhalation of contaminated air, has increased tenfold in adolescents in Belarus since 1986 with cases in adults also rising. Cases in children up to the age of 14 also increased, but that number has since reduced due to many of that age group being born after the event.

The impact of the contaminated air has also affected animals, crops and water supplies and the effects are still widely felt to this day. Radiation levels around Chernobyl will remain far higher than average for many millennia.

DID YOU KNOW? *At least 30 of the 50 rods needed to be inserted to be safe; when the plant exploded only six were inserted*

Countdown to disaster

Find out how history's worst nuclear accident played out

1 Safety switches
The safety switches were intentionally turned off to allow the experiment to run without intervention

2 Rods dropped
Control rods were lowered to reduce power output, but the power reduced too much too quickly

3 Rods raised
In order to get the plant working again, the rods were raised causing a rapid increase in production

4 Water heating
The all-important cooling water began to overheat, turning to steam and failing to cool the reactor

5 Emergency
Pressing the emergency button lowered the rods again, but they displaced the remaining water

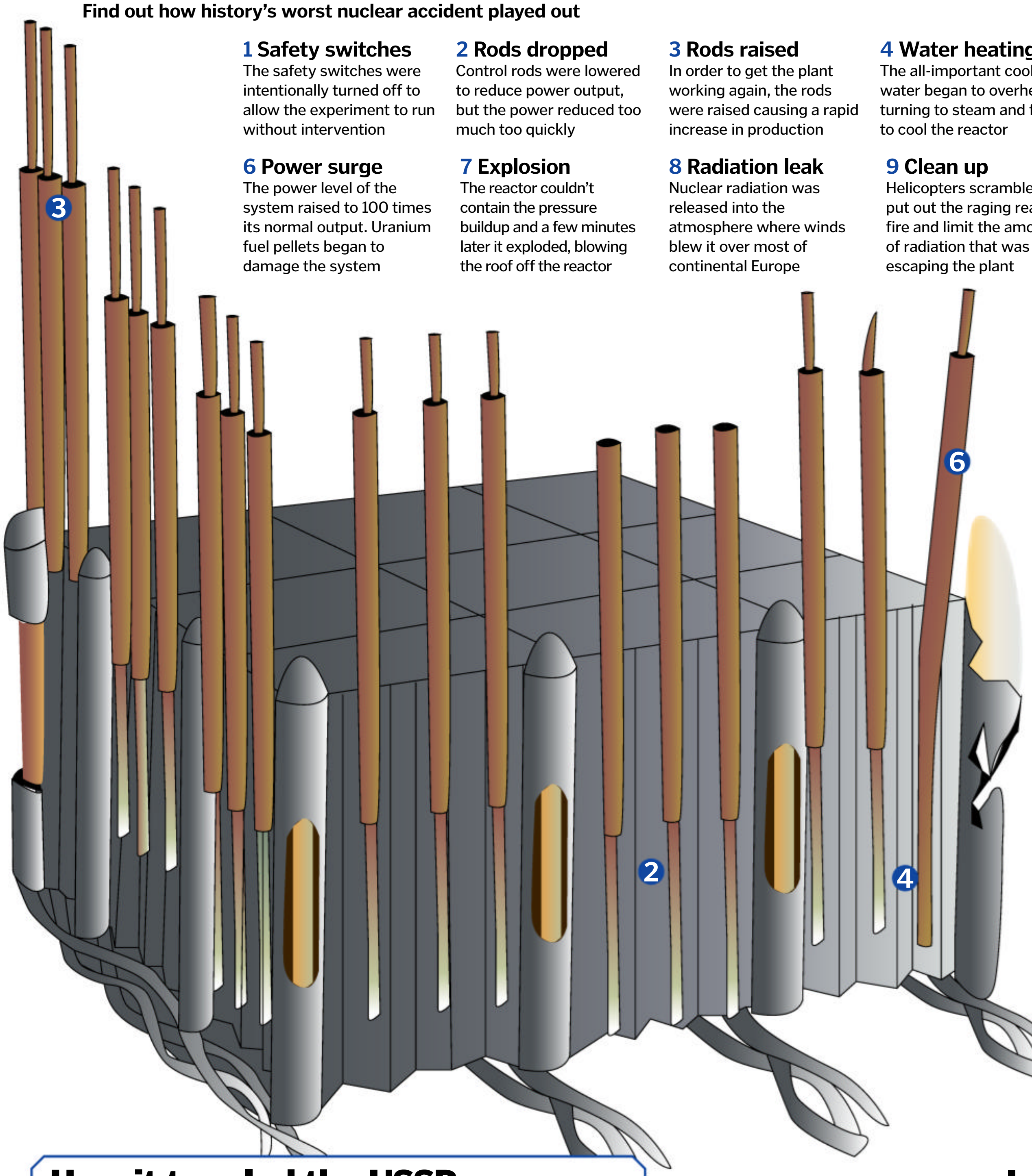
6 Power surge
The power level of the system raised to 100 times its normal output. Uranium fuel pellets began to damage the system

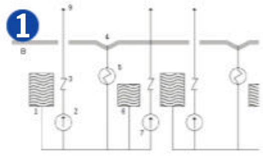
7 Explosion
The reactor couldn't contain the pressure buildup and a few minutes later it exploded, blowing the roof off the reactor

8 Radiation leak
Nuclear radiation was released into the atmosphere where winds blew it over most of continental Europe

9 Clean up
Helicopters scrambled to put out the raging reactor fire and limit the amount of radiation that was escaping the plant

10 Sarcophagus
A concrete shell was hastily constructed and placed over the nuclear plant to limit the release of radiation from Chernobyl





How it toppled the USSR

The leader of the Soviet Union at the time of the Chernobyl disaster, Mikhail Gorbachev, has claimed that the incident was a key factor in the demise of the USSR.

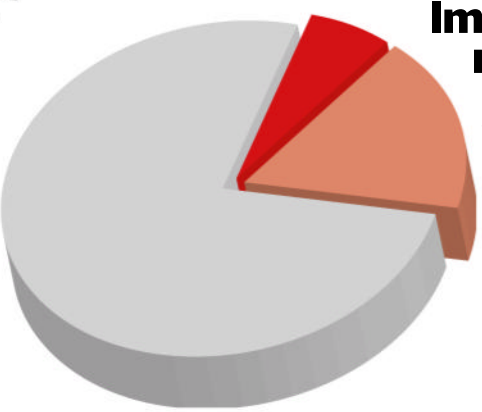
The government's response to the disaster was to try and cover it up as much as possible, with barely any official announcement of it and no warning to residents in the surrounding area as to the dangers of radioactive poisoning. It took a radioactive cloud that passed over Sweden to bring the event to the world's attention.

Furious at the lack of information and protection they had received, especially as Gorbachev had promised a new era of political clarity and honesty, citizens railed against the political system.

The general public lost faith in the government and the government in turn lost control of the general public. Five years later, the Soviet Union was dissolved, with Gorbachev quoted as saying, "The nuclear meltdown at Chernobyl […] was perhaps the real cause of the collapse of the Soviet Union."

Impact of the meltdown

How many were directly affected by the disaster?



🟥 **55,000** 6.4% died from radiation

🟧 **150,000** 17.4% were left disabled

⬜ **655,000** 76.2% underwent medical supervision

© Corbis; Thinkstock

WEAPONS & WAR

048 **History's deadliest warriors**
The lethal fighters that struck fear through the ages

054 **Spies through history**
Discover the secrets of espionage through the ages

060 **Meet the musketeers**
The origins of this popular military unit

062 **Sikorsky MH-60 Black Hawk**
How did this incredible war machine revolutionise aerial warfare?

060
Meet the musketeers

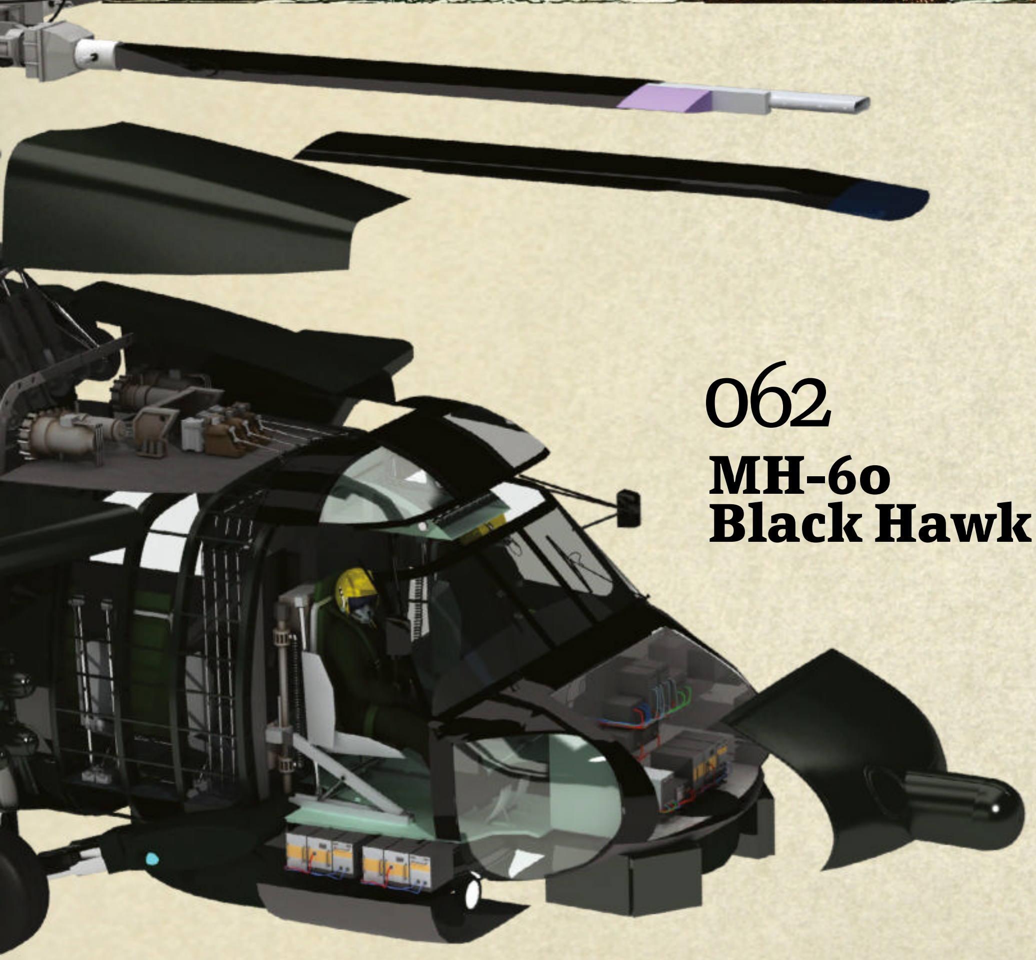
DANGER
JET
INTAKE

Spies through history

054

048

History's deadliest warriors

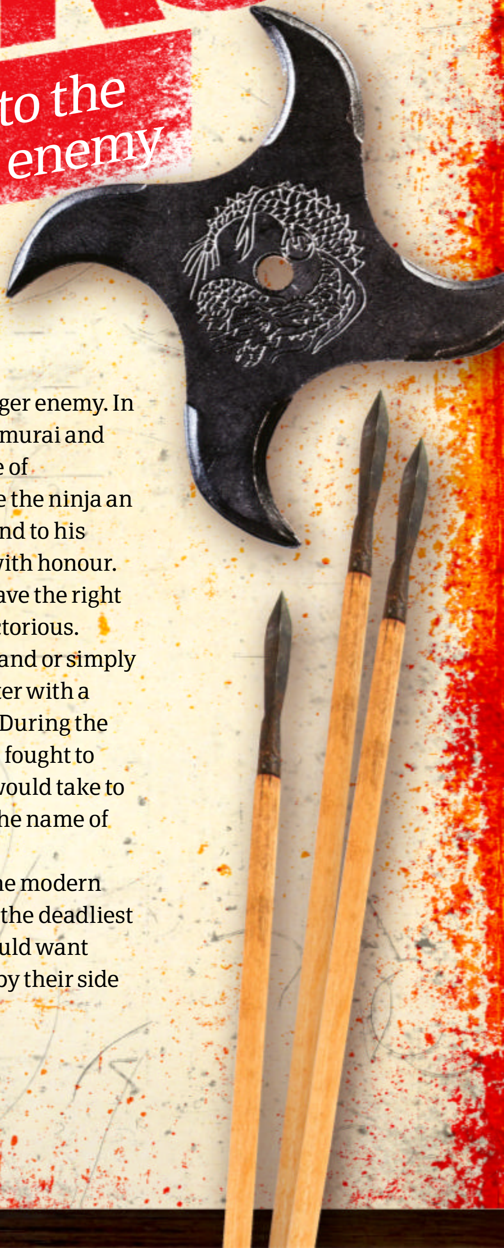


062

MH-60 Black Hawk

HISTORY'S DEADLIEST WARRIORS

Lethal fighters who could strike fear into the hearts of even the most battle-hardened enemy



Throughout history, many soldiers from across the world have been contenders for the title of the deadliest warrior, but who really was the most formidable? It takes more than just sheer strength or bloodlust to be considered a legendary fighter.

Most important of all is weaponry; even the toughest soldier can be defeated in a one-on-one dual by a rival with superior firepower. As the old adage goes, don't bring a knife to a gunfight, and the best fighters are always equipped for the job, whether it's a huge pitched battle or a covert operation. A popular theory as to why Custer's men were trounced at Little Bighorn was the fact that the Sioux warriors may have wielded superior rifles to the US Army.

Just as essential as having the right tools is using the right tactics. With a well-planned and efficiently executed strategy, soldiers can outmanoeuvre and outthink a numerically superior force or a physically stronger enemy. In a hypothetical battle between a samurai and ninja of Japan, for example, the use of underhand tactics could easily give the ninja an upper hand against a samurai bound to his moral code and obligated to fight with honour.

Finally, a deadly warrior must have the right attitude and appetite to emerge victorious. Whether it's to protect their homeland or simply earn a wage as a mercenary, a fighter with a purpose is much more dangerous. During the Crusades, Christians and Muslims fought to uphold their religious values and would take to the battlefield again and again in the name of their faith.

Ranging from ancient times to the modern era, read on to learn about some of the deadliest warriors in history. Any soldier would want these legendary fighters standing by their side on the eve of battle.

CIRCA 476-206 BCE

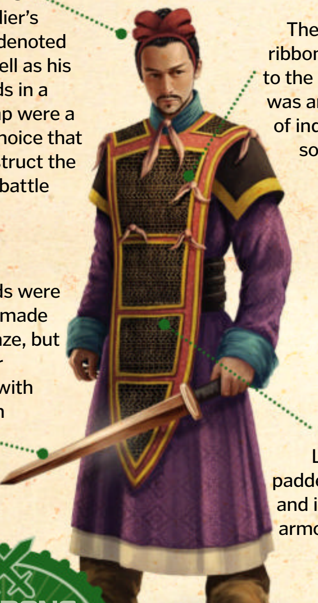
Qin soldier

The military that fought ruthlessly to unify China

The Qin Dynasty was a period of great progress for China. The new emperor Qin Shi Huang made a series of sweeping changes that unified the country and modernised its military. In came China's first professional conscripted army, staffed by formidable soldiers and led by skilled generals. Qin soldiers used some of the most advanced weapons during the era, from sharp iron swords to powerful crossbows.

Their role on the battlefield as shock infantry was supplemented by more heavily armed foot soldiers, as well as flanking cavalry and chariots. The warriors that battled on horseback were held in the saddle by a new invention, the stirrup, giving them greater balance than their adversaries. Some of their enemies were worthy foes, in particular, nomadic tribes from the north with mounted archers. But fuelled by a desire for conquest and loyalty to their emperor, the Qin often held their own in battle.

Notable battle... QIN'S WARS OF UNIFICATION 236-221 BCE



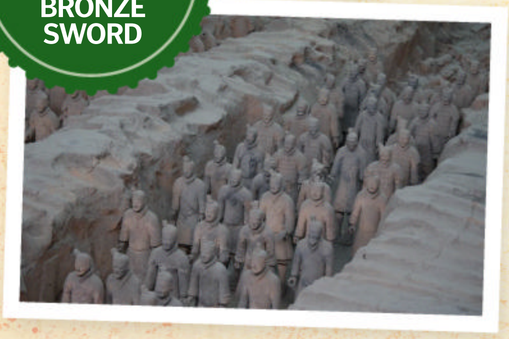
Hairstyle
A Qin soldier's hairstyle denoted rank as well as his unit. Braids in a leather cap were a popular choice that didn't obstruct the fighter in battle

Ribbons
The number of ribbons fastened to the chest plate was another way of indicating the soldier's rank

Bronze sword
Qin swords were originally made from bronze, but were later replaced with tough iron

Armour
Light robes, padded trousers and iron-riveted armour allowed the well-protected warriors to remain nimble

WEAPONS OF CHOICE
CROSSBOW, BRONZE SWORD



The Terracotta Army is made up of ceramic versions of Qin soldiers. The statues were buried with the emperor in his tomb to accompany him in the afterlife

CIRCA 400 BCE-476 CE

Roman legionary

One of the ancient world's finest armies comprised dedicated, hardened soldiers

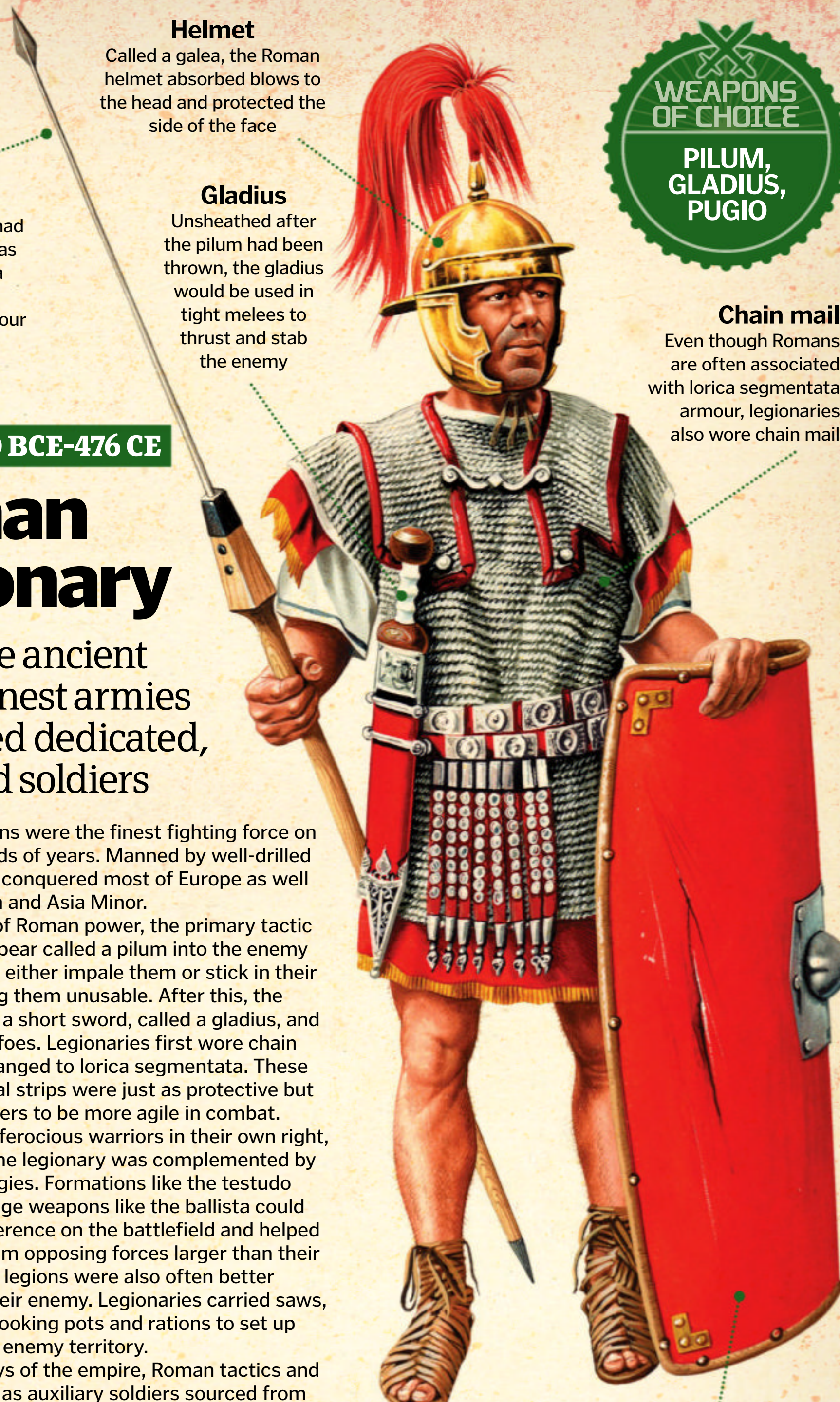
The Roman legions were the finest fighting force on Earth for hundreds of years. Manned by well-drilled legionaries, they conquered most of Europe as well as parts of Africa and Asia Minor.

At the height of Roman power, the primary tactic was to throw a spear called a pilum into the enemy masses. It would either impale them or stick in their shields, rendering them unusable. After this, the legionaries drew a short sword, called a gladius, and charged at their foes. Legionaries first wore chain mail but later changed to lorica segmentata. These overlapping metal strips were just as protective but allowed the soldiers to be more agile in combat.

Despite being ferocious warriors in their own right, the prowess of the legionary was complemented by intelligent strategies. Formations like the testudo (tortoise) and siege weapons like the ballista could often be the difference on the battlefield and helped legions overwhelm opposing forces larger than their own. The Roman legions were also often better prepared than their enemy. Legionaries carried saws, rope, pickaxes, cooking pots and rations to set up camps deep into enemy territory.

In the later days of the empire, Roman tactics and armour changed as auxiliary soldiers sourced from around the empire began to fill the ranks. Being a legionary was a well-respected career in the empire, and victorious generals were treated to celebratory processions on their return to Rome.

Notable battle...
BATTLE OF PYDNA, 168 BCE



Helmet
Called a galea, the Roman helmet absorbed blows to the head and protected the side of the face

Pilum
A type of heavy javelin, the pilum had a strong tip and was weighted in such a way that it could pierce enemy armour

Gladius
Unsheathed after the pilum had been thrown, the gladius would be used in tight melees to thrust and stab the enemy

Chain mail
Even though Romans are often associated with lorica segmentata armour, legionaries also wore chain mail

WEAPONS OF CHOICE
PILUM, GLADIUS, PUGIO

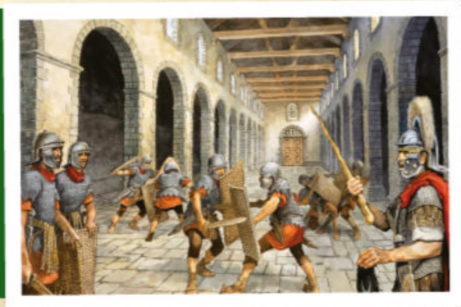
Sandals
The Roman legionary marched in thick, heavy sandals that were stuffed with wool or fur in cold weather

Scutum
The iconic rectangular wooden shield protected the body and was glued carefully so it could interlink in the testudo formation

© WIKI; Mary Evans

Roman training

Legionaries were trained to be superior to their enemies. To become part of the legion, the soldiers would be judged on their height, their eyesight and their physical fitness. Recruits were taken on from the age of 18 and would be expected to march up to 30 kilometres a day. A huge emphasis was placed on training, from battlefield formations to swordplay. In specialised training schools, legionaries fought with wooden swords and could lose rations if they did not perform well.



8TH-11TH CENTURY

Viking raider

These brutal warriors devastated coastal towns right across Europe

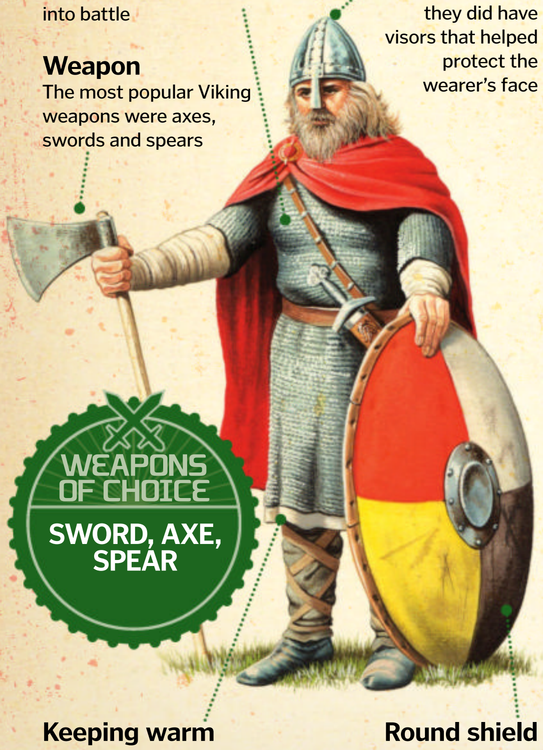
Anglo-Saxon Britain was assaulted by a series of raids by Norsemen from Scandinavia. Pitching their longboats up on the shore, Vikings pillaged the local area before returning to their ships with valuable plunder. As time wore on, the attacks became more and more frequent and an area known as the Danelaw was established, encompassing northern and eastern England. Wealthy Vikings used double-edged swords, but the majority of fighters carried axes or spears into battle.

The Vikings didn't have standardised tactics, giving them greater variety on the battlefield. Warriors called berserkers went into battle brandishing huge two-handed axes that they used to hew down anyone who got in their way.

The Vikings had a rich appetite for battle as well as an upbringing based on the necessity of war. The longboat helped initiate rapid attacks that would strike an enemy before its forces could retaliate. These tactics helped them conquer not just parts of the British Isles but also territories in Spain, France and Russia. The emperor of the Byzantine city of Constantinople even had his own Norse bodyguards, the Varangian guard, who were some of the toughest mercenaries of the era.

Notable battle...

ATTACK ON LINDISFARNE 793 CE



Ringed mail
Chain mail coats were worn by some chieftains into battle

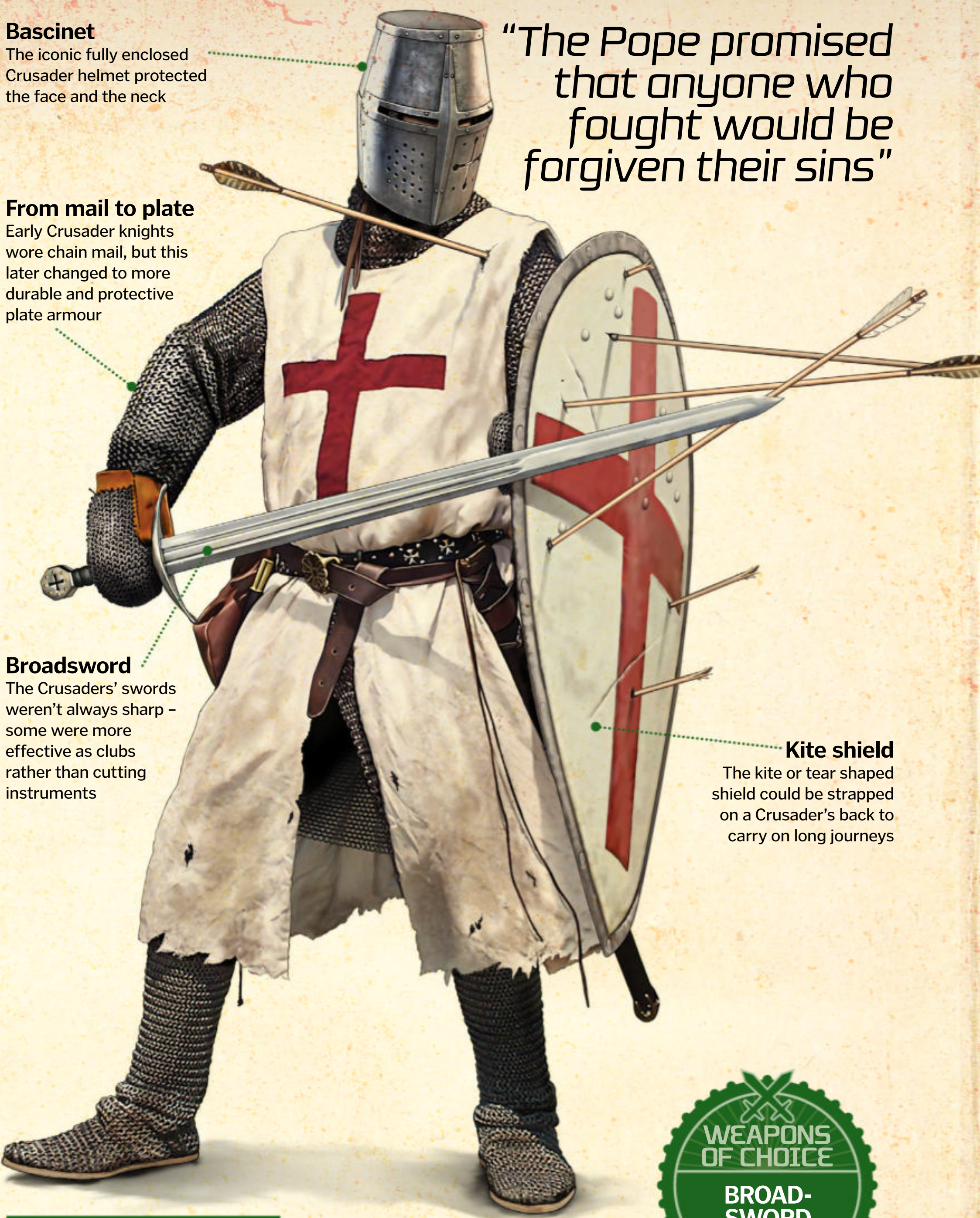
Iron dome
Viking helmets did not have horns but they did have visors that helped protect the wearer's face

Weapon
The most popular Viking weapons were axes, swords and spears

WEAPONS OF CHOICE
SWORD, AXE, SPEAR

Keeping warm
In cold temperatures on land and at sea, a thick under-tunic was worn below the armour

Round shield
Circular shields were made of wood and iron and attached to the side of a longboat when travelling



Bascinet
The iconic fully enclosed Crusader helmet protected the face and the neck

"The Pope promised that anyone who fought would be forgiven their sins"

From mail to plate
Early Crusader knights wore chain mail, but this later changed to more durable and protective plate armour

Broadsword
The Crusaders' swords weren't always sharp – some were more effective as clubs rather than cutting instruments

Kite shield
The kite or tear shaped shield could be strapped on a Crusader's back to carry on long journeys

WEAPONS OF CHOICE
BROAD-SWORD

11TH-13TH CENTURY

Crusader knight

Clad in protective armour, these western knights fought in holy wars approved by the Pope

Between 1096 and 1272 there were a total of nine crusades to the Holy Land. The foot soldiers of these Christian armies fought to reclaim Muslim-controlled cities like Jerusalem, which they believed to be rightfully theirs. Pope Urban II initiated the First Crusade, promising that anyone who fought would be forgiven for their sins.

The Crusaders' iconic look was completed with a red cross emblazoned on a white surcoat. This was worn to identify each knight as a Christian as well as protecting the metal armour from the hot Sun.

The knights fought both on horseback and on foot as the ownership of the Holy Land changed hands between the Crusaders and the Saracens frequently. Many bloody battles were fought as huge losses mounted on both sides. Both forces still continued fighting undeterred though, fuelled by religious passion and an unwavering belief that they were dying in their god's name.

Notable battles...

SIEGES OF ANTIOCH (1097-1098), SIDON (1110) AND ACRE (1189-1191)

DID YOU KNOW? *The Vikings may have been the first Europeans to land in the Americas, centuries before Columbus*

1325-1521

Aztec eagle warrior

The warriors of the Sun who formed an elite fighting force

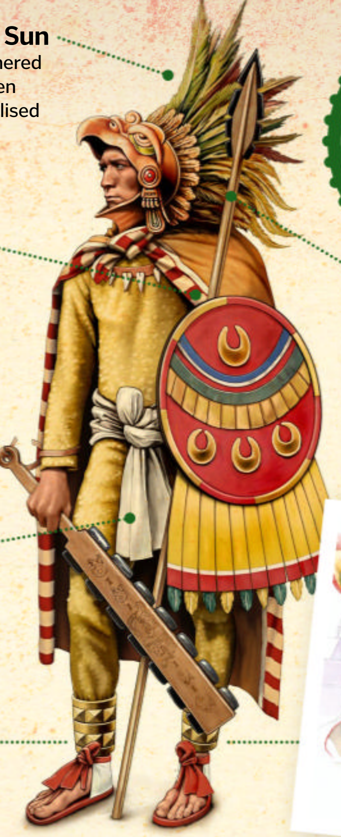
Prior to the arrival of the Spanish conquistadors, the Aztec Empire dominated vast areas of modern-day Mexico. One of the infantry types that helped maintain control were the eagle warriors. Along with jaguar warriors, they formed an elite unit of Aztec society that was renowned for its military prowess.

To be part of the society, an Aztec had to prove their worth on the battlefield by capturing a set number of enemy soldiers to be used in sacrificial rituals. The aim of returning foes for sacrifice meant that most of the eagle warrior's weapons were designed to wound, not kill.

The Aztec society did not have the technology to smelt metal so they used the world around them to arm themselves. Rocks were collected as ammunition for slings, turkey feathers were used to fletch arrows and tunics were soaked in salt so they would crystallise and harden. Eagle warriors also carried unique weapons like the atlatl, a spear and dart throwing device, and the macuahuitl, a blunt wooden paddle with sharp glass blades protruding from it.

Notable battles...

FALL OF TENOCHTITLÁN 1521, BATTLE OF OTUMBA 1520



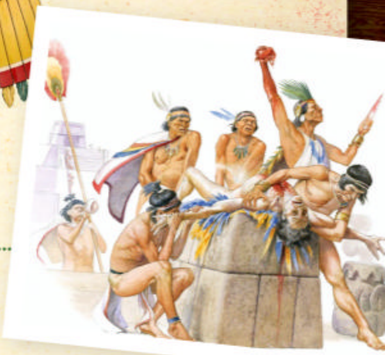
Warriors of the Sun
Warriors wore a feathered headdress and wooden headgear that symbolised a bird's open beak

Protection
The warriors wore a quilted cotton tunic and carried a brightly coloured, feathered, round leather shield called a chimalli

Macuahuitl
A favourite weapon was the macuahuitl, a wooden paddle with glass made from volcanic rock embedded in it

WEAPONS OF CHOICE
MACUAHUITL, ATLATL

Other weapons
As well as spears, eagle warriors carried slings and bows tipped with either rock, bone or obsidian



Captive soldiers were often gruesomely sacrificed to the gods

10TH-17TH CENTURY

Ninja

With stealth as a priority, ninjas struck silently from the shadows

Among the most famous assassins in history, the ninja were dangerous adversaries in feudal Japan. Also known as shinobi, in folklore the ninja were first formed to fight back against oppression from the ruling class by a rogue samurai who went against the bushido code.

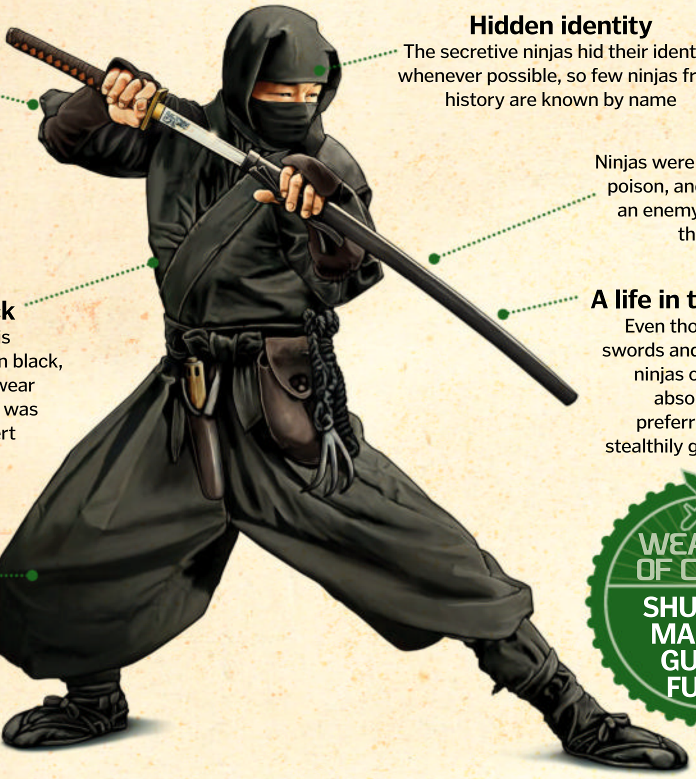
They practised ninjutsu, the art of stealth, which taught special ninja combat skills and how to remain hidden. Ninja were the opposite of the samurai, and rather than having codes based on honour like Bushido, they would happily covertly kill their enemies, an act considered immoral by the samurai. But this didn't mean that the two were enemies, instead, the ninja were often employed to aid the samurai.

Contrary to popular depictions, ninjas didn't just wear black; they dressed to blend in, so they would just as likely be clad in civilian clothing to avoid detection. In combat, ninjas would use standard Japanese weapons of the era, but also wielded their own special equipment. The shuko was a small device used for traction when scaling walls and a tessen was an inconspicuous metal fan that could be used as a weapon.

Ninja combat may not have been just reserved for men, either; tales of female ninjas, or kunoichi, described their dressing as servants or dancers to secretly infiltrate forts and compounds to get closer to a target.

Notable battles...

NANBOKUCHO WARS 1331-1392, ONIN WAR 1467-1477



Sneaky operations
Ninjas were especially useful in sieges, infiltrating castles and distracting the surprised defenders

Dressed in black
The archetypal ninja is dressed head to toe in black, but they would only wear this attire for when it was needed, such as covert operations at night

Martial arts training
Ninjas were trained in martial arts like jujitsu, so they were a dangerous foe even when unarmed

Hidden identity
The secretive ninjas hid their identity whenever possible, so few ninjas from history are known by name

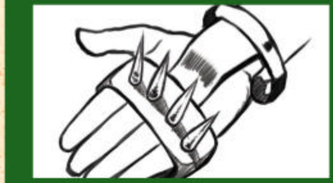
Weaponry
Ninjas were experts at using poison, and would add it to an enemy's food or infuse their blades with it

A life in the shadows
Even though they carried swords and other weapons, ninjas only fought when absolutely necessary, preferring a silent kill or stealthily gathering secrets

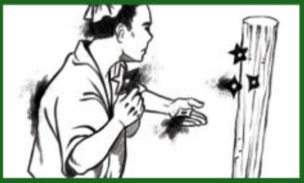
WEAPONS OF CHOICE
SHURIKEN, MANRIKI-GUSARI, FUKIYA

Ninja tool kit

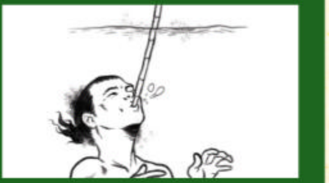
An array of weapons and accessories helped ensure ninjas always had a trick up their sleeves



Kakute
Similar to a knuckleduster, kakute were small, spiked iron rings worn around the fingers. They were an asset in hand-to-hand combat.



Shuriken
These throwing stars could quickly and secretly eliminate targets from distance. They were small enough to be hidden in clothing.



Fukiya
Blowpipes launched poison darts at enemies or sent secret messages to allies. They could also be used as breathing straws.

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14TH-19TH CENTURY

Ottoman janissary

WEAPONS OF CHOICE
BOW, ARQUEBUS, SWORD

The elite infantry of the Ottoman Empire

For centuries the Ottoman Empire's mighty army was led by janissaries. The first force was formed around 1380 by Christian prisoners captured after successful Ottoman campaigns in Europe. Aged between six and 14, they were taken from their homeland and bred for battle. After being drafted into the army, they became the property of the sultan and acted as his personal bodyguards.

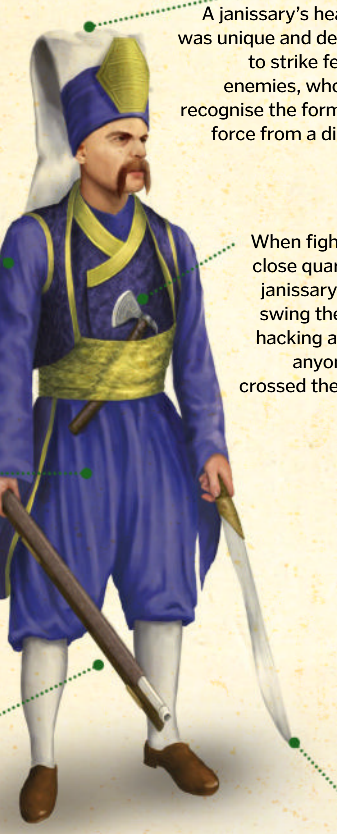
The janissaries were forced to observe strict rules and were trained to a high standard as disciplined and skilful warriors. As the sultan's most trusted guards, the companies resided in barracks and were constantly drilled for a life of war. The janissary commander was called the agha and ranked above other commanders in the Ottoman military.

Janissaries used swords and rifles as they moved quickly to overwhelm fortresses or to outflank cavalry. On the battlefield, janissaries were recognisable due to their distinctive headgear. They also fought at sea, using their rifles to fire at mariners on enemy ships. They gained a reputation as some of the best marksmen in the world, deploying devastating walls of fire.

In peacetime they also served in Ottoman cities as policemen. At their peak in the early 19th century, there were over 100,000 janissaries and the Ottoman Empire represented one of the finest fighting forces in the world.

Notable battles...

SIEGE OF CONSTANTINOPLE 1453
BATTLE OF MOHÁCS 1526



Robe
A felt robe was worn in place of armour. Lightweight and flexible, it allowed janissaries to move swiftly and engage in naval operations

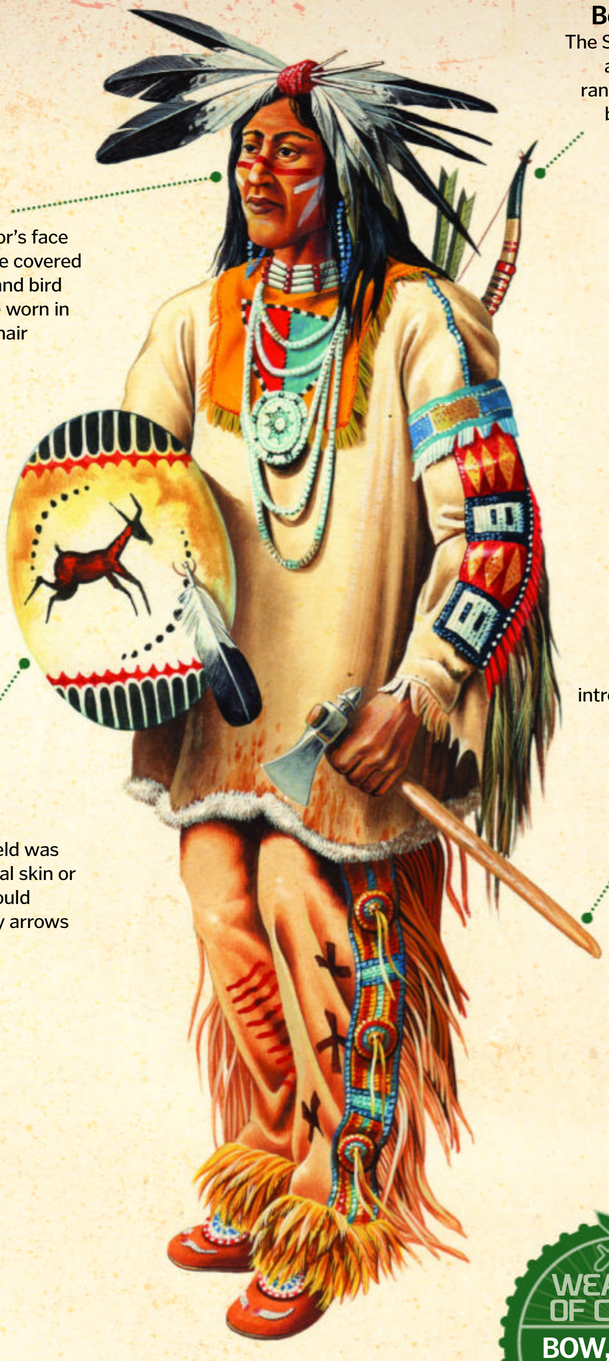
Headgear
A janissary's headgear was unique and designed to strike fear into enemies, who could recognise the formidable force from a distance

Axe
When fighting at close quarters, a janissary would swing their axe, hacking away at anyone that crossed their path

Breeches
Long robes were stuffed into breeches so they were out of the way both during marching and in the midst of battle

Primary weapon
Starting off as archers, janissaries soon modernised and wielded arquebuses, becoming some of the most accurate marksmen in the world

Secondary weapon
With its curved blade the yatagan sword was useful on the battlefield as well as an enduring symbol of the janissary



Bow and arrow
The Sioux bow shot iron arrows over a short range, and some were backed with animal tendons to provide extra power

War paint
A Sioux warrior's face and body were covered in war paint, and bird feathers were worn in the warrior's hair

Tomahawk
Before rifles were introduced by settlers, axes were used as both melee and projectile weapons

Shield
The small shield was made of animal skin or leather and could deflect enemy arrows

WEAPONS OF CHOICE
BOW, SPEAR, AXE, RIFLE, COUP STICK

PRE-EUROPEAN COLONISATION-1890

Sioux warrior

Native American warriors who preferred to count coups rather than draw blood

Unlike many of the other warriors on this list, the Sioux seldom fought in large numbers. They preferred to attack in small raiding parties that focused on stealing horses or avenging a fallen comrade rather than occupying territory.

The Sioux, like other Native American tribes, did not believe in the ownership of land, but they did compete with rivals like the Crow for hunting and living space in the summer months. Both Sitting Bull and Crazy Horse were Sioux warriors, and it was any young man's ambition to prove their status within a tribe. In Sioux warrior societies it wasn't considered heroic to die, and instead the ultimate show of courage was to touch an enemy with a coup stick.

Enemies that were killed were scalped. This, the Sioux believed, prevented enemies from revisiting warriors in the afterlife, and scalps would be hung as spoils of war outside tipis and on spears and shields.

Notable battle...

BATTLE OF LITTLE BIGHORN 1876

DID YOU KNOW? *Janissary colonels were nicknamed 'soup cooks' due to their ladle insignia, a sign of loyalty to the sultan*

PRE-EUROPEAN COLONISATION-19TH CENTURY

Zulu warrior

The men who defied the European imperialists

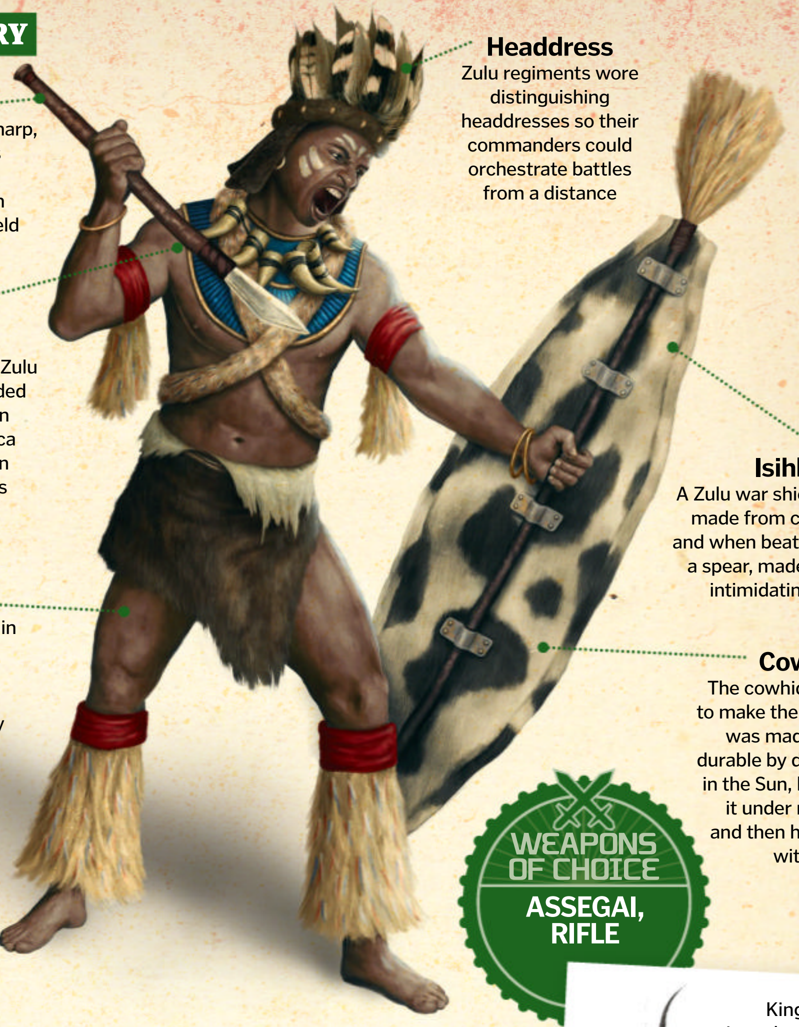
Zulus were divided up into regiments of hundreds or thousands of warriors called an ibutho. Younger unmarried men comprised the main fighting force, and to maximise their time in service, chiefs often didn't let their troops marry until their mid-30s. When a Zulu was married, they could choose to leave the ibutho and from then on were only required to fight in times of war.

Shields were only issued in wartime; Zulus were not allowed to own one in peacetime to help quell potential civil war. Younger regiments tended to have darker shields while more experienced contingents defended themselves with lighter coloured versions. The shields themselves were used to knock enemies off balance before stabbing them with short spears. As well as being traditional, it helped Zulu leaders identify different units on the battlefield. There wasn't a standing army and Zulu warriors returned to their homes between conflicts.

The army didn't have any sort of supply system and lived off the land. This made operations short but often decisive. The Zulus knew the lay of their land better than anyone, which made ambush attacks highly effective. Their prowess in battle enabled the Zulus to conquer rival tribes and made them more than a match for the invading Europeans.

Notable battles…

BATTLE OF ISANDLWANA 1879, BATTLE OF RORKE'S DRIFT 1879



Assegai
Equipped with a sharp, pointed blade, this spear was used to stab enemies from behind a large shield

Modern firearms
As well as spears, Zulu warriors also wielded rifles that had been imported into Africa by settlers or taken from defeated foes

Stamina
With no supply train or heavy armour, Zulu forces could cover over 30 kilometres in a day

Headdress
Zulu regiments wore distinguishing headdresses so their commanders could orchestrate battles from a distance

Isihlangu
A Zulu war shield was made from cowhide and when beaten with a spear, made a loud intimidating noise

Cowhide
The cowhide used to make the shields was made extra durable by drying it in the Sun, burying it under manure and then hitting it with rocks

WEAPONS OF CHOICE
ASSEGAI, RIFLE

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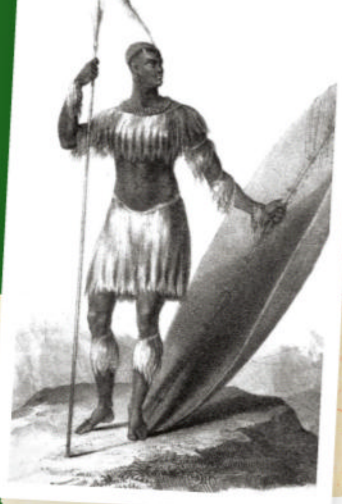
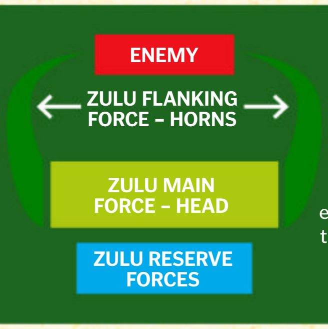


King Shaka introduced new military tactics

Horns of the buffalo formation

When the Zulus delivered a crushing defeat to the British at the Battle of Isandlwana in 1879, they had their tactics to thank. The formation was pioneered by Zulu king Shaka and involved a strong central core of warriors flanked by horns – two units of light troops. As the enemy moved to engage the strongest Zulu units in the centre, they would be flanked and encircled. This strategy was devastatingly effective against local tribes but was less successful against the British, especially at Rorke's Drift, where concentrated rifle fire prevented the Zulus from getting in close. However, against the scattered British forces at Isandlwana, it led to an emphatic victory.



The two flanking horns would pressure the enemy toward the main body of the Zulu force

1815-PRESENT

Gurkha

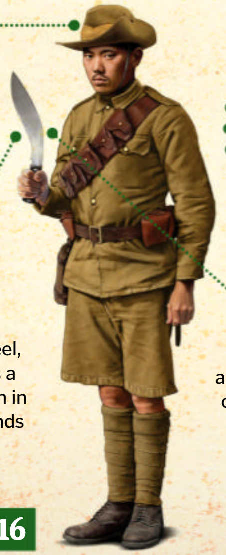
Loyal and fearless, they were a vital asset to Britain in WWI

During World War I, Gurkhas were some of the finest soldiers on the side of the Allied powers. They travelled from their native Nepal to many theatres of the war, including the treacherous cliffs of Gallipoli and the blood-soaked fields of the Western Front. Time and again, the brave Gurkhas led assaults on key positions.

Gurkhas were first enlisted by the British in 1815 and around 3,500 still serve in the British Army. Almost 2,000 were awarded gallantry awards during the Great War and several have received the Victoria Cross. Their motto is 'better to die than be a coward'.

Notable battles…

BATTLE OF LOOS 1915, GALLIPOLI CAMPAIGN 1915-1916



Battlefield courage
Gurkha regiments universally wore this headgear during WWI for traditional reasons

Kukri
A distinctive curved knife made of tempered steel, the kukri was a lethal weapon in practiced hands

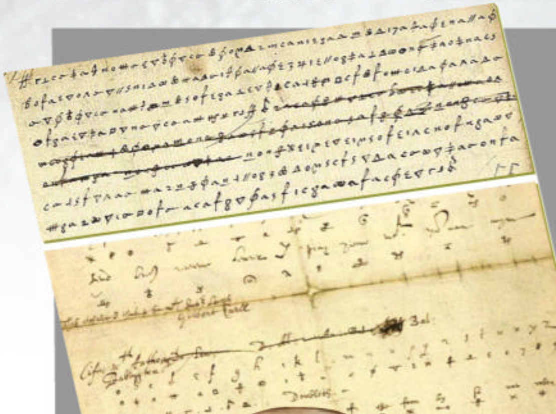
Weapon and tool
The kukri can also be used to chop food and wood. An old legend stated that it had to draw blood every time it was drawn

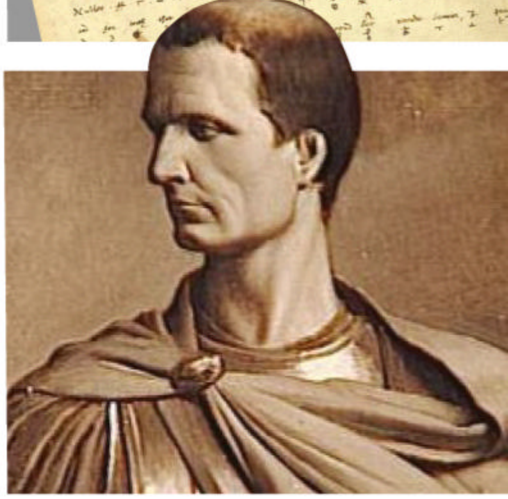
WEAPONS OF CHOICE
KUKRI

Over 200,000 Gurkhas served as allies of the British in the two World Wars

SPIES THROUGH HISTORY

The secrets of espionage through the ages





The principle of gathering confidential information, from secret documents to military tactics, has proved invaluable for rulers, empires and governments throughout history. Covertly collecting information about enemies, and even allies, provided nations with the opportunity for military, political or economic gain.

Espionage is the gathering of secret information, and the methods used changed dramatically as technology developed. In ancient Rome, letters could be intercepted en route to their intended recipient. In an attempt to prevent this, Julius Caesar invented one of the earliest-known ciphers – a code used to disguise messages – to stop enemy spies reading his secret military communications.

In the 20th century, espionage was particularly important during the two World Wars, as nations established huge intelligence networks in an effort to stay one step ahead of the enemy. Some estimate that deciphering the Nazi's 'uncrackable' Enigma machines (used to encode messages) helped shorten World War Two by several years, saving countless lives.

During the Cold War, with the threat of nuclear war between the US and Soviet Union looming, strategic intelligence was vital and influenced tactics on both sides. Spies disguised gadgets as everyday objects to help gather information, from coat button cameras to microphones hidden in shoe heels.

Counterintelligence operations continue to be incredibly important to this day. Security services across the world work to protect their citizens against threats to national interests, conducting counter-terrorism operations and tackling cyber crime.

DID YOU KNOW? 'Eavesdropping' originates from the Middle Ages when spies would listen from the eaves (roofs) of buildings

Ancient espionage

How intelligence was gathered by ancient civilisations

In the first cities of ancient Mesopotamia and ancient Egypt, spying was an effective way for kings and pharaohs to monitor the population, as well as to discover enemy weaknesses. The ancient Egyptians used court spies to root out disloyal subjects, and they were also among the first to develop poisons for sabotage or assassinations.

With no spy gadgets at their disposal, eavesdropping on conversations, intercepting communications and scouting enemy movements were the key methods used to gather useful intelligence. Resourceful techniques were developed to ensure written messages remained secret, including codes and trick inks.

The ancient Greeks excelled at espionage and subterfuge. The legendary tale of the Trojan horse became a symbol of their cunning and deceptive military tactics. They developed efficient methods of communicating important messages between cities, including a fire signal system known as hydraulic semaphore.

Another tactic used by the Greeks to prevent communications being intercepted was carving important messages into wood and then covering it in wax. The wooden board would then be sent to an ally who would melt the wax to read the message. A more gruesome method was writing on the outside of an inflated animal bladder, before deflating it and packing it into a flask. The document could then be transported anywhere unnoticed until it was opened, inflated and read.

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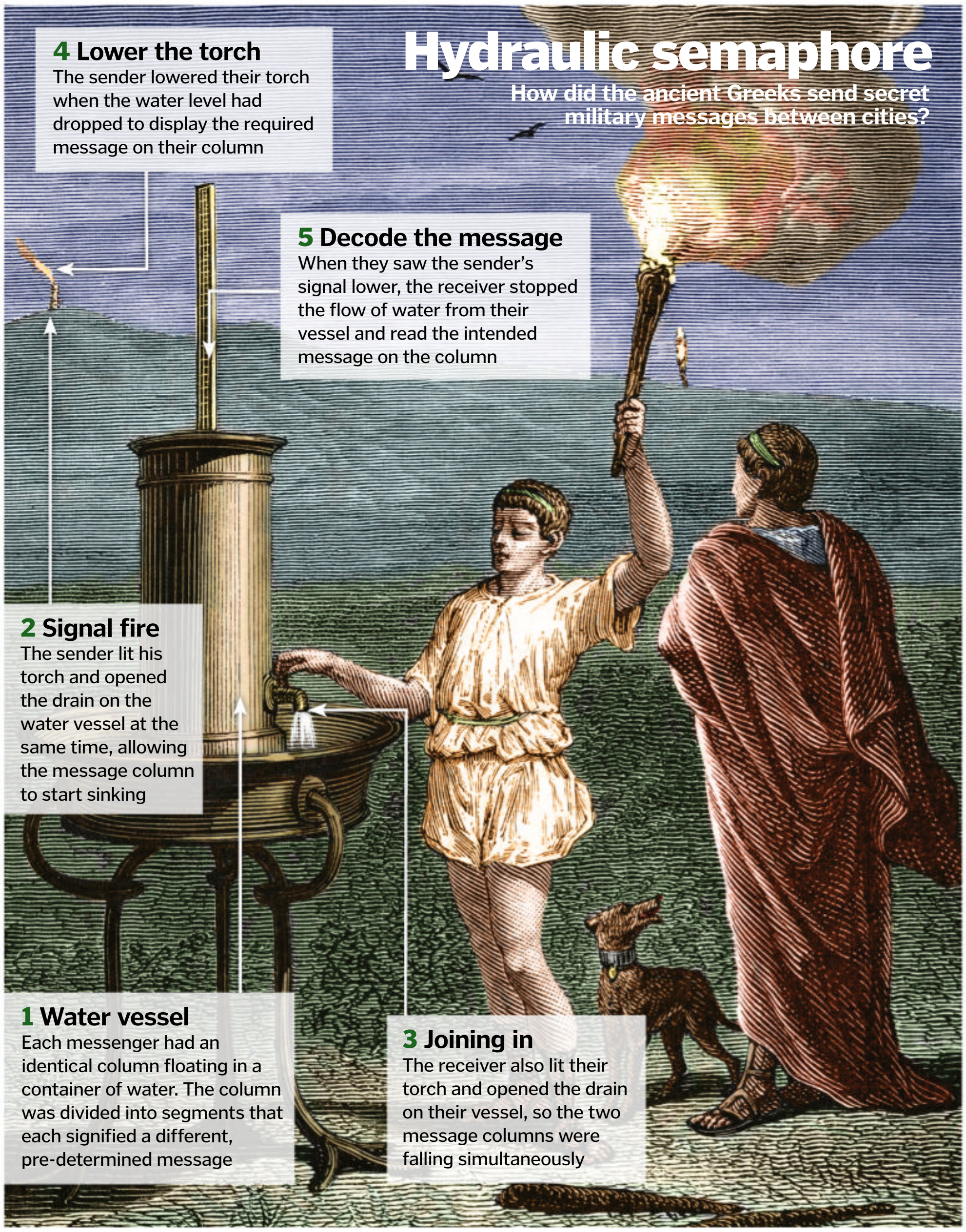
Hydraulic semaphore

How did the ancient Greeks send secret military messages between cities?



1 Water vessel
Each messenger had an identical column floating in a container of water. The column was divided into segments that each signified a different, pre-determined message

2 Signal fire
The sender lit his torch and opened the drain on the water vessel at the same time, allowing the message column to start sinking

3 Joining in
The receiver also lit their torch and opened the drain on their vessel, so the two message columns were falling simultaneously

4 Lower the torch
The sender lowered their torch when the water level had dropped to display the required message on their column

5 Decode the message
When they saw the sender's signal lower, the receiver stopped the flow of water from their vessel and read the intended message on the column

> "Eavesdropping, intercepting messages and scouting enemy movements were the key methods used to gather intelligence"

Julius Caesar's speculatores

The Roman Republic was a fragmented, unruly place and keeping hold of power was never easy. Many rulers hired bodyguards for protection, but Julius Caesar saw the value of secret surveillance and used spies called 'speculatores' to gather intelligence of potential revolts. This reconnaissance network helped Caesar keep abreast of goings on both domestically and internationally. Some sources suggest that Caesar was aware of the Roman Senate-led plot to assassinate him.

Not even Caesar's speculatores could prevent his assassination

The Mongol spy network

United under leader Genghis Khan, the Mongols were one of the most feared military forces of the 12th and 13th centuries as they rampaged across Asia. However, this mighty army would not have been as successful had it not been for an extensive intelligence network. Genghis Khan gathered information from trade merchants, who had an in-depth knowledge of the areas he wished to conquer. This intelligence allowed the Mongols to pinpoint weaknesses in enemy territories.

Spies' information gave the Mongols an advantage when conquering new lands

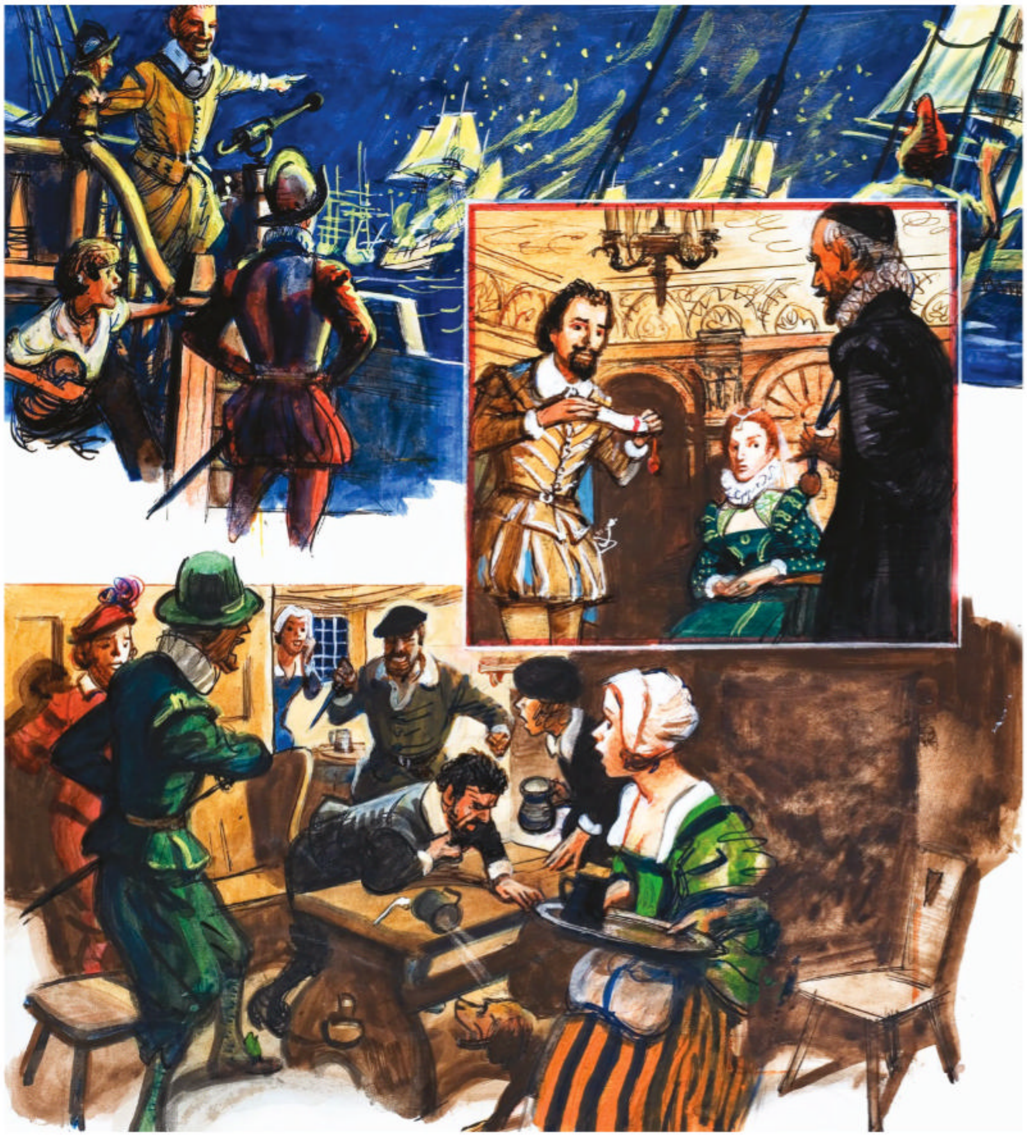
Elizabethan espionage

The final Tudor monarch created a secret service network that helped keep her on the throne

As a Protestant queen with no heirs, Elizabeth I's reign was threatened by those who would have preferred the Catholic Mary Queen of Scots. With the threat of assassination, the Queen set up a network of spies to protect her against dissidents and uncover foreign plots. Head of Elizabeth's secret service was Sir Francis Walsingham, a Protestant lawyer. Those hired as spies were among the greatest minds in the land; scholars, scientists and linguists were all tasked with protecting the vulnerable monarchy.

Technological advancements also aided the intelligence network. Invisible ink made from milk or lemon juice was first utilised in this period, allowing secret messages to be revealed by warming the paper over a candle. Cryptography became more advanced, and the spy network needed to be able to both write and decipher different codes.

A series of plots to overthrow or assassinate the Queen were uncovered during her reign. The intelligence gathered by Elizabeth's secret service most likely saved her life on more than one occasion. For example, after her imprisonment, Mary Queen of Scots maintained contact with the outside world by sending coded messages to her allies hidden in barrels of beer. Little did she know that the barrels were being smuggled by a double agent acting on behalf of Walsingham, who deciphered her messages and proved that Mary was involved in a plot to kill Elizabeth. Those involved, Mary included, were quickly caught, tried and executed for treason.

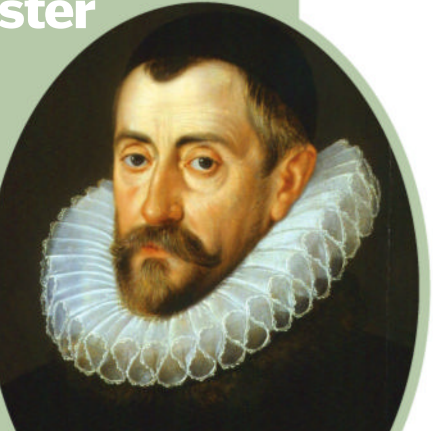


Agents in Elizabeth's spy network gathered information about the Spanish Armada's preparations

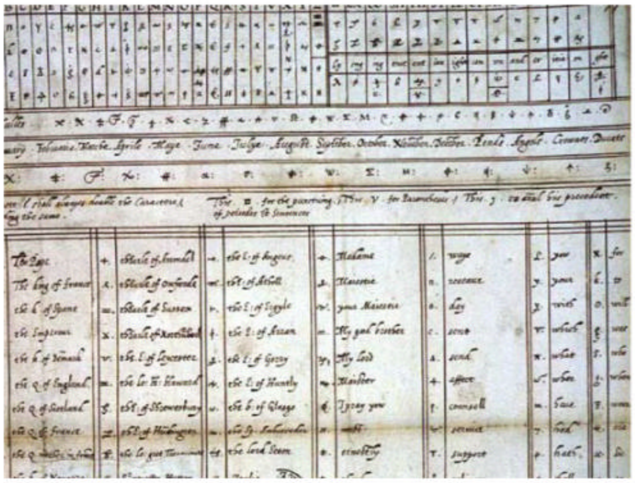
Elizabeth's spymaster

At the head of the Elizabethan spy network was the secretary of state, Sir Francis Walsingham. With threats coming from Catholic Spain, devout Protestant Walsingham built up a network of spies all over Europe – including prison informants and double agents – with the aim of gathering intelligence about the activities of Catholics, as well as political and economic information.

To ensure his agents were as effective as possible, Walsingham established a spy school to train new recruits. His network proved invaluable to national security after foiling several plots against the Queen, as well as providing intelligence about the Spanish Armada leading up to the attempted invasion in 1588.



Walsingham was provided with £2,000 a year to carry out his work

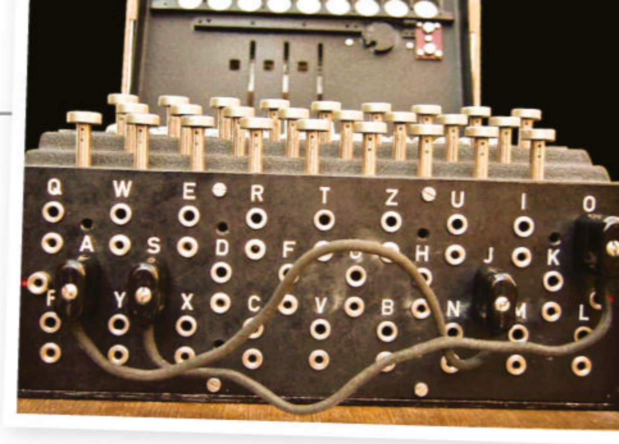


Mary sent secret messages to her allies using these cipher symbols, but Walsingam's spies decoded them

DID YOU KNOW? *By 1943, the bombes decoded 84,000 Enigma messages a month*

World War spies

How inventive spying strategies were used to try and win both global conflicts


On the front face of the Enigma machine was an electronic plugboard that could be used to swap pairs of letters, for an extra level of encryption

World War One may be remembered primarily for trench warfare, but behind the lines, spies were performing a vital role. One of the most successful spy networks during the war was codenamed 'La Dame Blanche'. With over 1,000 members, the organisation worked for the British, conducting valuable reconnaissance missions in German-occupied Belgium, spying on trains, roads and airfields.

The development of aircraft in the early 20th century meant that aerial reconnaissance was also a large part of the war. Both German and French planes took photos from above to examine troop movements. German intelligence greatly helped its divisions push forward on the Eastern Front. By acquiring secret documents and intercepting radio messages, they knew what moves the Russians would make.

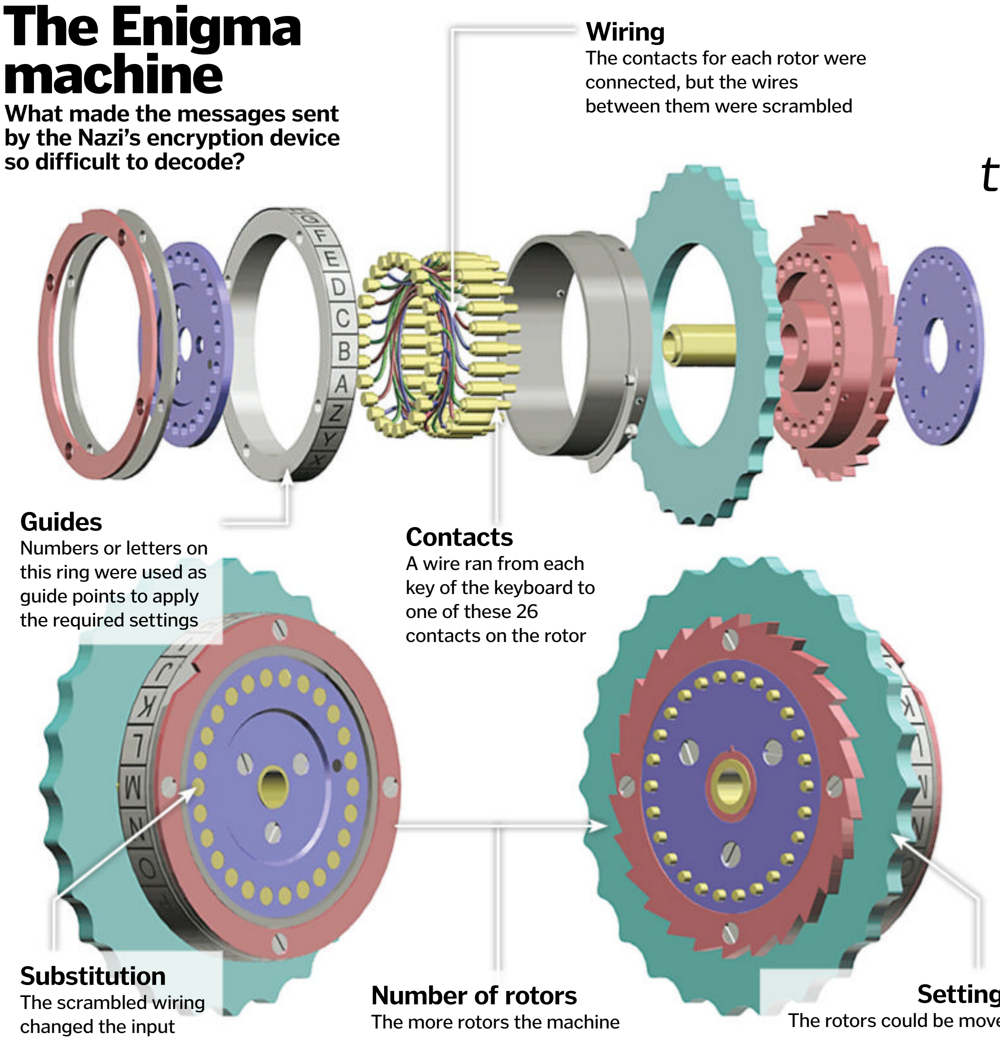
When World War Two began, espionage was still an instrumental part of warfare. Germany's military intelligence organisation, the Abwehr, was particularly effective during the occupation of the Netherlands. The group captured 52 Allied agents and 350 resistance fighters, some as soon as they parachuted in. Still under the illusion that they were supplying their Dutch allies, the British unwittingly provided the Germans with 570 boxes of weapons and ammunition.

Most famously, the Nazi's Enigma machines were used to ensure their army's messages remained secure. To send a signal, an operator typed in their message and then scrambled it using a series of rotors, which would reproduce the message as a jumble of different letters. The receiver would need to know the exact settings used by the sender in order to decode the original message on their own machine. The settings were frequently changed, and a typical army-issue Enigma machine could have over 150 million trillion different settings, so cracking the code was considered impossible. The British eventually managed to decipher Enigma after teams of mathematicians and code-breakers at Bletchley Park developed computers known as bombes that could work out the machine's settings based on an intercepted coded message. Some historians estimate that the intelligence the Allies gathered by breaking the Enigma code helped shorten the war by two years.

"A typical army-issue Enigma machine could have over 150 million trillion different settings"

The Enigma machine

What made the messages sent by the Nazi's encryption device so difficult to decode?



Wiring
The contacts for each rotor were connected, but the wires between them were scrambled

Guides
Numbers or letters on this ring were used as guide points to apply the required settings

Contacts
A wire ran from each key of the keyboard to one of these 26 contacts on the rotor

Substitution
The scrambled wiring changed the input and output letters between the rotors

Number of rotors
The more rotors the machine contained, the greater the number of possible settings

Settings
The rotors could be moved manually to change the machine's settings

World War spies

The shady double agents that provided intelligence to the opposition

Howard Burnham
Burnham was an intelligence officer for the French government in World War One and often hid his spying equipment in his wooden leg.

Mata Hari
A Dutch dancer, Hari spied for the Germans before being caught by the French and sent to the firing squad in 1917.

Virginia Hall
Hall was a US spy during World War Two who provided support, information and training for resistance fighters and the Allies in occupied France.

Takeo Yoshikawa
Living in Hawaii during World War Two, Japanese spy Yoshikawa provided intelligence to his country ahead of the surprise attack on Pearl Harbor.

© Look & Learn; WIKI

Cold War espionage

After the Second World War, a new era of spying emerged during a bitter rivalry

A decades-long power struggle between the US and the USSR began after the collapse of the Third Reich. The nations held opposing ideologies – capitalism versus communism – and had a mutual distrust of one another's intentions. Tensions rose as both powers entered into an arms race and the threat of a devastating nuclear war grew. Espionage was one of the primary methods used to try and break the deadlock. Each of the two superpowers was determined to gain the upper hand, so spies were sent all over the world to gather intelligence about the enemy.

One of the most infamous spy networks behind the Iron Curtain was the Ministry for State Security, commonly known as the Stasi. Operating in East Berlin, the organisation used brutal methods to monitor the activities of the East German capital's citizens. Stasi soldiers would shoot citizens who strayed out of line or tried to make a break for the West.

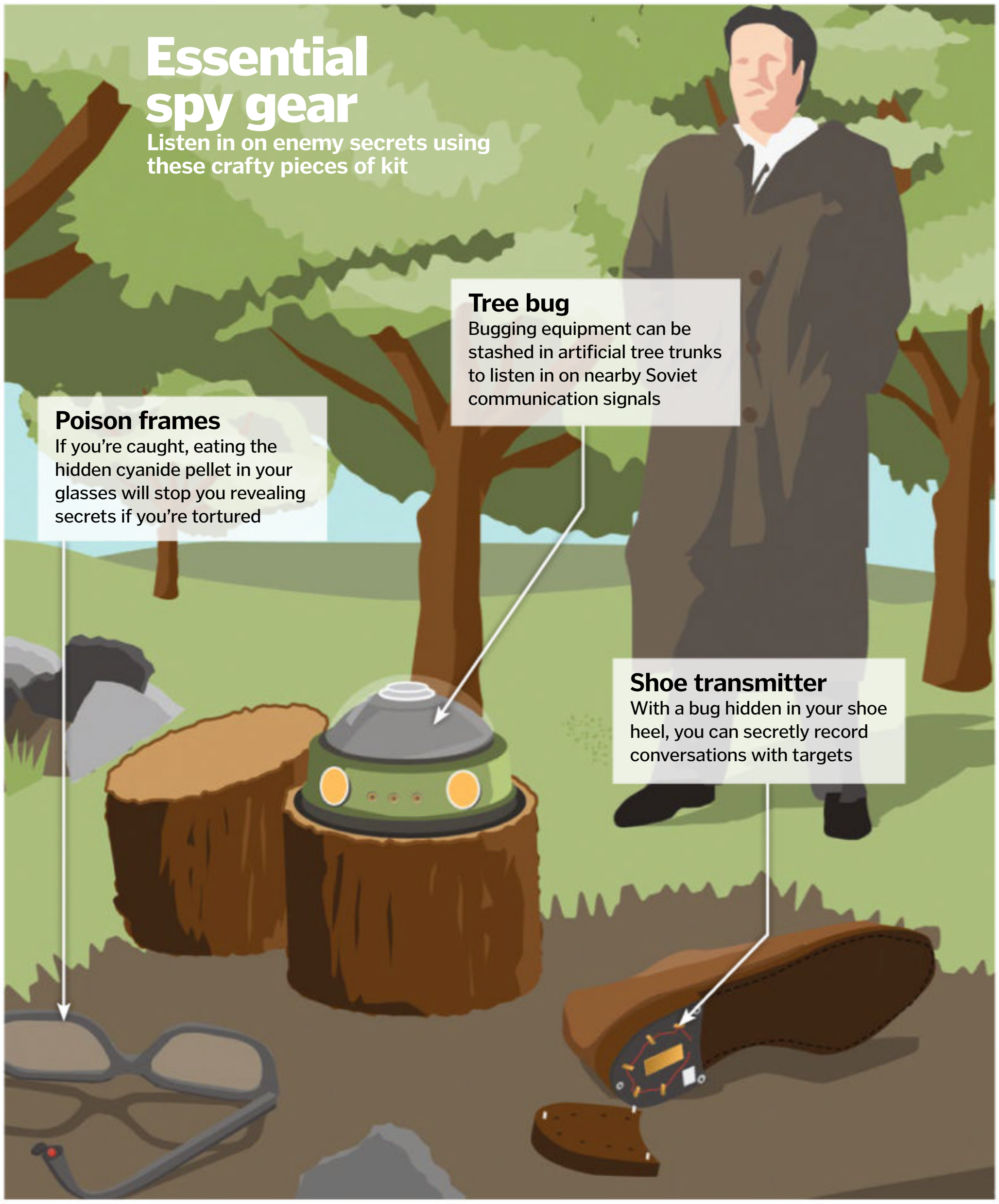
> *"The Blackbird could travel at more than three times the speed of sound"*

After World War Two, the US set up Project Shamrock and Project Minaret, espionage exercises to monitor all telegraph information entering and leaving the country. Despite this, there were a number of spies operating in the US for the Soviets, gathering information on nuclear weapons, military movements and new technologies.

Aerial reconnaissance continued to play a huge part in intelligence operations. The CIA located Soviet ballistic missiles using spy satellites under the Corona Program. After a CIA pilot was shot down while flying over the USSR in a U-2 spy plane in 1960, the US realised that continuing to use these aircraft was too risky. In response, the record-breaking SR-71 Blackbird was constructed. The Blackbird could travel at more than three times the speed of sound, and reach altitudes high enough to avoid radar detection. The reconnaissance jet even had special radar-absorbing black paint.

Essential spy gear

Listen in on enemy secrets using these crafty pieces of kit

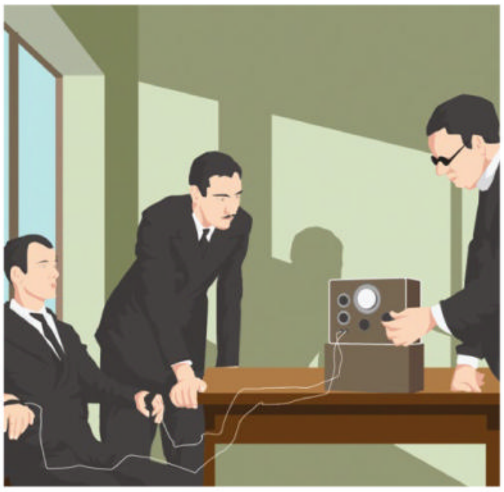


Tree bug
Bugging equipment can be stashed in artificial tree trunks to listen in on nearby Soviet communication signals

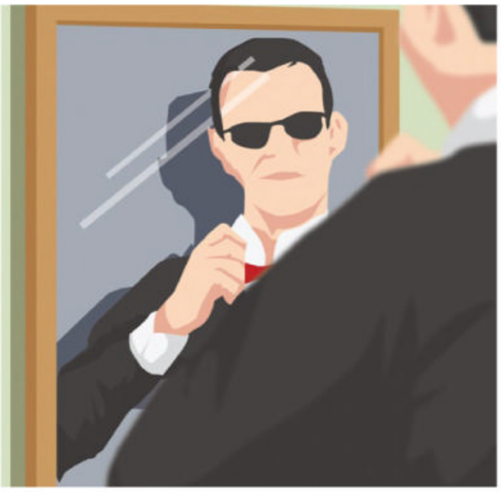
Poison frames
If you're caught, eating the hidden cyanide pellet in your glasses will stop you revealing secrets if you're tortured

Shoe transmitter
With a bug hidden in your shoe heel, you can secretly record conversations with targets

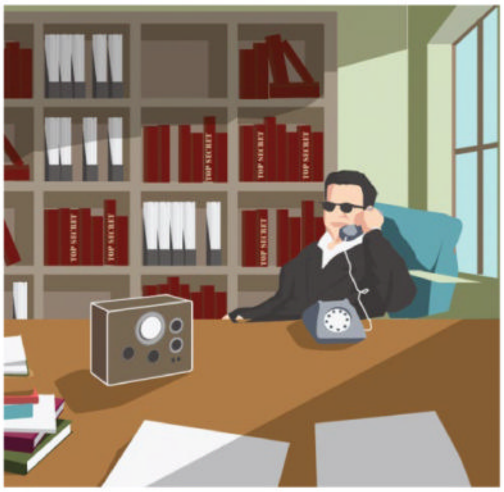
DID YOU KNOW? *MI5 headquarters, Thames House, contains 5km of miniature railway that is used to transport paper documents*



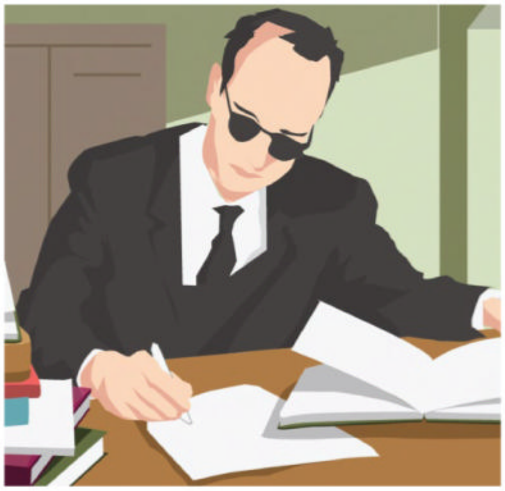
1 CIA training
Only the most successful recruits are selected to be agents. An intensive course including both physical and mental tasks will show who's capable of being a spy.



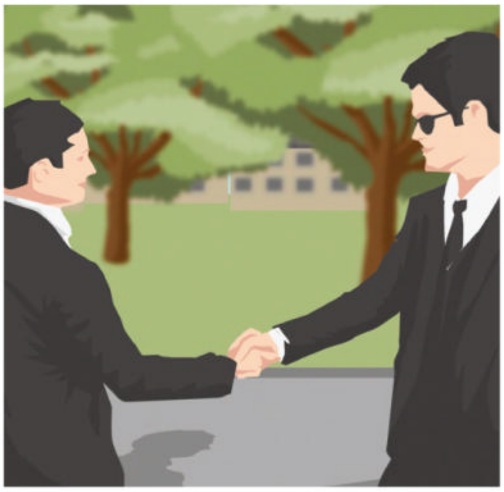
2 The life of a spy
To avoid arousing suspicion, you must create a believable persona and backstory. The finest agents appear to live completely ordinary lives.



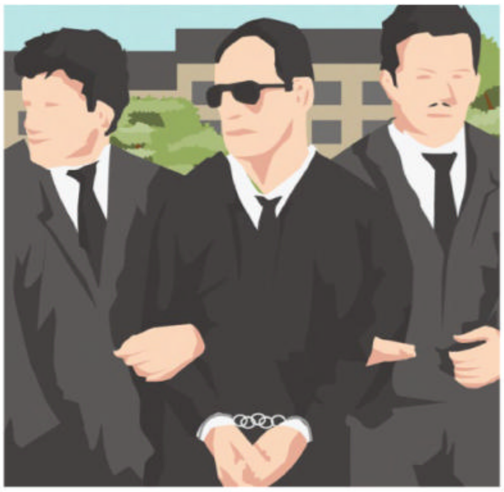
3 Data collection
Your main objective is to determine the Soviets' intentions towards the US. The intelligence you gather could give your country a huge advantage.



4 Decryption skills
The best spies have a talent for code-breaking. Soviet intelligence agents encrypt their messages so you will have to decipher them to reveal any secret plans.



5 Break morale
With your spy persona, you have the ability to spread rumours behind enemy lines. Create fake news stories to cause unrest among citizens or the leadership.



6 Avoid capture at all costs
If you're caught, it's all over. Espionage is a serious offence during the Cold War, carrying the penalty of a long prison sentence or execution.

The 'Illegals Program'

In 2010, ten Russian agents were arrested in the US. Upon interrogation by the FBI, it was revealed that they had been active in the US for years as sleeper agents, spies who weren't always active but resided in the US if ever needed for duty. Known as 'Illegals', some of the spies posed as American citizens with fake names and backgrounds, and had normal jobs. They had been instructed to make contact with academics to obtain secret intelligence that they could report back to Russia. All ten of the spies were charged with conspiracy to act as an agent of a foreign government, and were released into Russian custody as part of a prisoner exchange.

Anna Chapman was arrested after an FBI operation exposed her as a sleeper agent

Spies wanted

How intelligence agencies operate in the internet age

Most of us share our lives with friends and family on social media, but this data creates problems if you want to be a spy. Intelligence agencies are struggling to operate effectively in a time where false identities and backstories are hard to create. Most people will leave traces of their real lives online, and facial recognition software can potentially use these traces to link an undercover agent to their true identity.

To try and combat this, the UK's Secret Intelligence Service (SIS, or MI6) were planning to hire nearly 1,000 new staff by 2020. In a statement, SIS chief Alex Younger explained: "The information revolution fundamentally changes our operating environment. In five years' time there will be two sorts of intelligence services – those that understand this fact and have prospered, and those that don't and haven't."

Vauxhall Cross in London has been the SIS's headquarters since 1994

Meet the musketeers

One of the most popular military units for centuries, musketeers fought in battles and protected esteemed rulers all the way from France to India

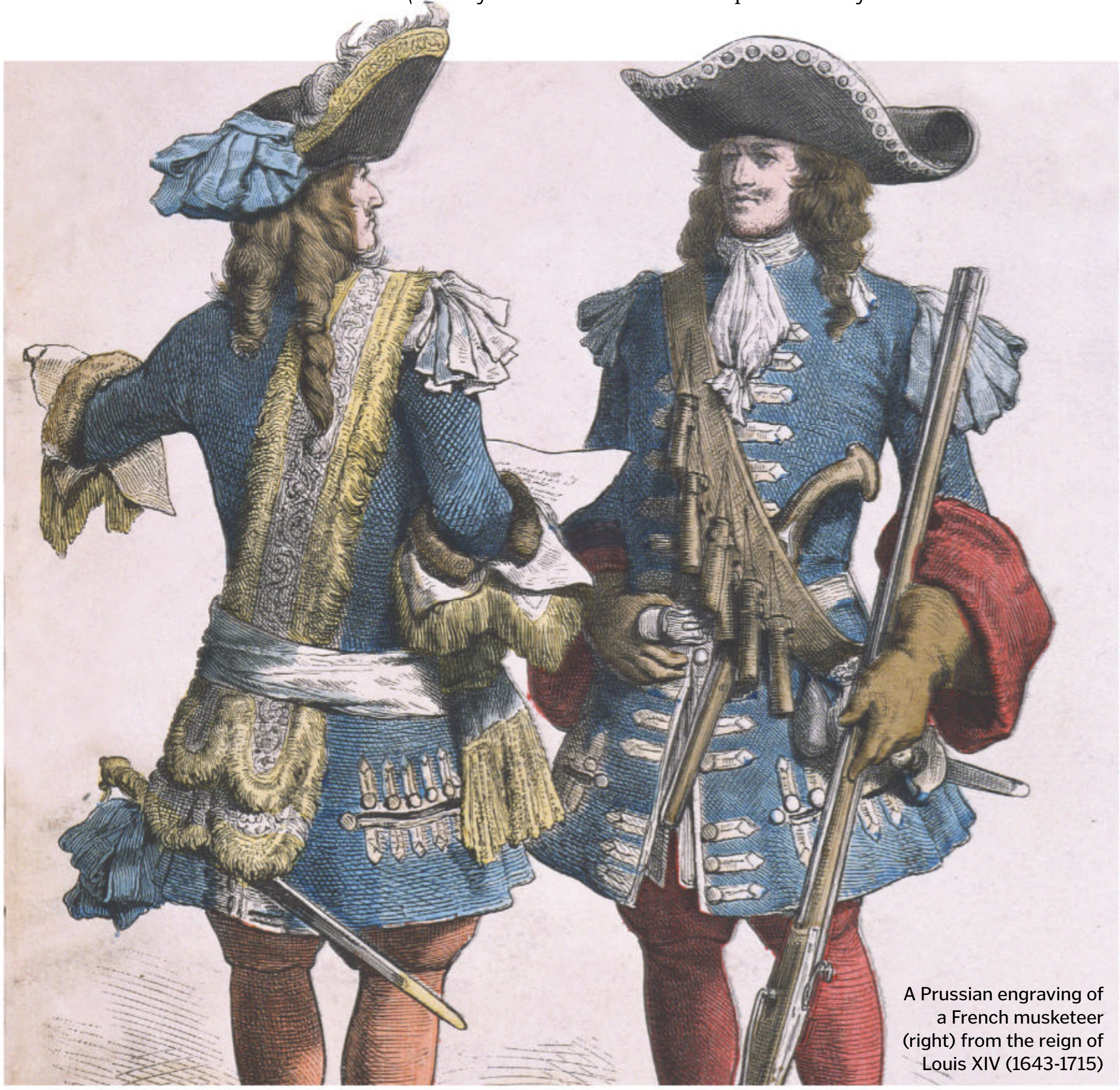
Musketeers were an early form of soldier who were armed with muskets. They acted as a bridge unit between traditional infantry – which fought on foot and typically hand-to-hand with swords and other melee weapons – and dragoons, a type of light cavalry armed with long-ranged weapons. This granted them a level of versatility and flexibility most prized on the battlefield, with musketeer units typically reserved for the protection of nobility or, in many Western nations, royalty.

While musketeers as a unit are older (see 'Musketeer origins' boxout for details), they didn't emerge in Europe until the 16th century, with the concept only really taking off on a large scale in the early-17th century.

While this particular era was dominated by the French musketeers of the Maison du Roi (the Royal Household) – upon which the fictional musketeers of Alexandre Dumas' *The Three Musketeers* are based – countries like Spain, Britain, Russia, Sweden, Poland and even India each developed their own musketeer units in this period and used them on the battlefield frequently.

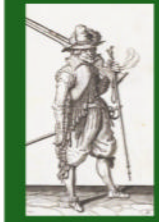
Musketeers as a common military unit were largely phased out by the middle of the 19th century, with a number of new developments in firearms rendering the musket obsolete. With the introduction of the rifle – which could shoot both farther and much faster than the musket – the rifleman unit would emerge, negating the need for the greater speed afforded by the mounted musketeer.

This, combined with the decline of many dynasties throughout Europe – notably the Ancien Régime of France during the French Revolution – saw all musketeer units permanently disbanded.



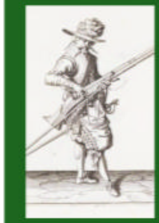
A Prussian engraving of a French musketeer (right) from the reign of Louis XIV (1643-1715)

How to fire a musket step-by-step



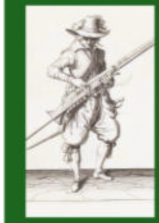
1 Carry

While marching to position the musket should be carried over the shoulder, with the firing rest secured in your off-hand.



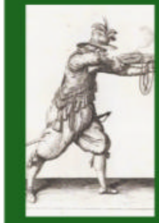
2 Firing prep

When firing is ordered, the musket is filled with priming powder, charge and ball, with the weapon held in a diagonal orientation.



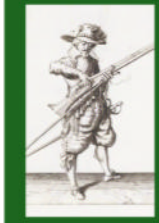
3 Insert fuse

The match fuse should then be cocked in the matchlock and blown on, ensuring at all times that the match doesn't extinguish.



4 Shoot

Draw up the musket while simultaneously securing the firing rest. Slot the musket in the rest's support brace, aim and fire.

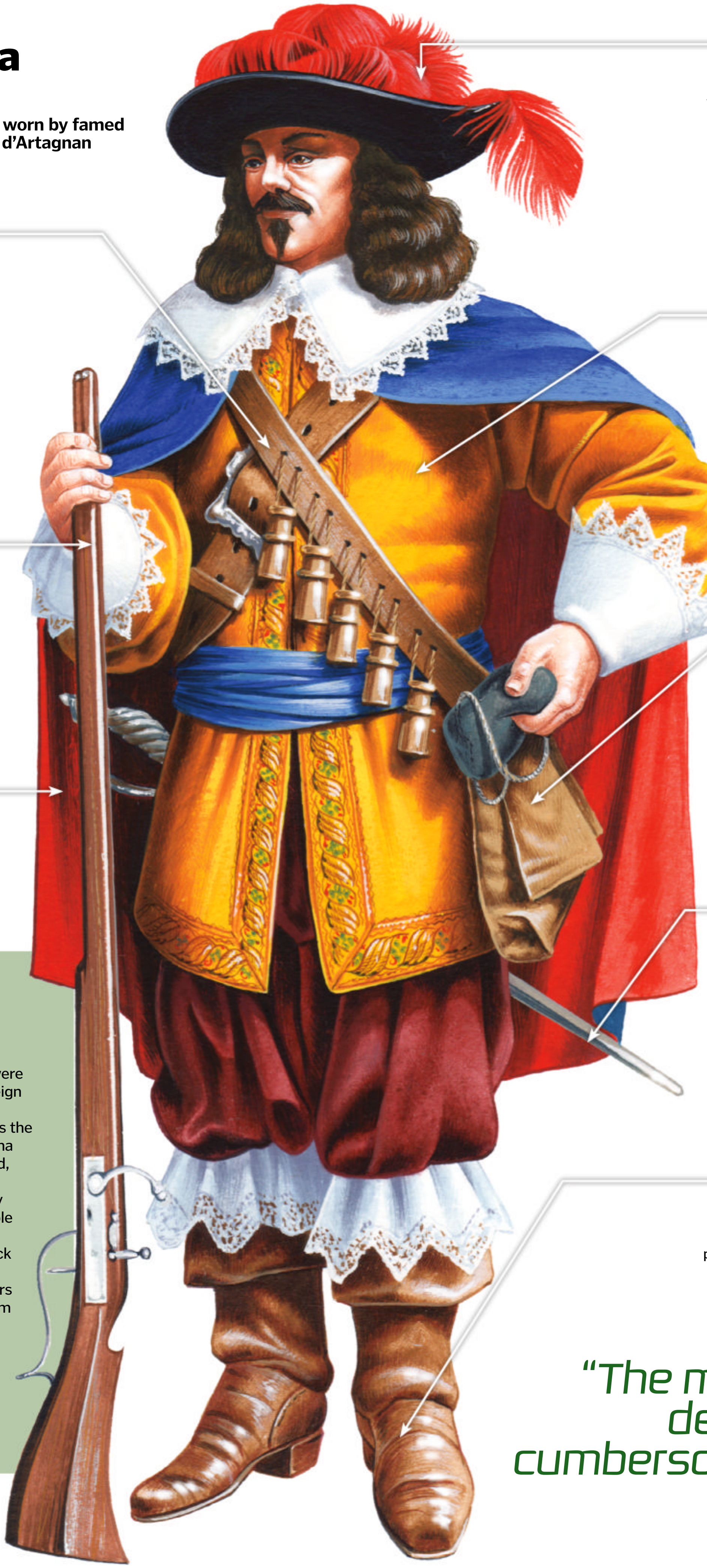


5 Withdraw

Bring the musket off its rest, draw it down to your side, then take the fuse off the musket and await further instructions from superiors.

Uniform of a musketeer

Check out the essential kit worn by famed musketeer captain, Comte d'Artagnan



Hat
Musketeers started off in the West wearing simply ornate hats, but by the early-19th century these evolved into metal helmets. They did remain decorative though, often with large feathered plumes attached

Bandolier
Bandoliers (a pocketed belt) and ammunition pouches/bags were a common accessory for musketeers, so they were always well supplied on the battlefield. These belts were strapped around the waist or chest

Tunic
Considerably more elaborate than standard infantry, musketeer tunics and – in later periods – cuirasses, favoured manoeuvrability over armoured protection

Musket
The musketeer's primary weapon, the musket was deadly, albeit cumbersome to use. Its slow reload rate restricted use to four shots per minute at best

Holdall
As musketeers were on the road during much of their military service, each carried their own holdall to store food and personal belongings

Cape
A feature associated more with earlier iterations of musketeers, the cape offered some protection from the elements while travelling

Sword
As musketeers were trained to fight both on horseback like dragoons and on foot like infantry, they were also equipped with a sword for hand-to-hand engagements

Boots
Boots were an important part of the musketeer's uniform, both communicating their prestigious position and providing good support on the ground and on horseback (some had spurs attached)

Musketeer origins

Unlike the musketeers of the Maison du Roi – the Royal Household of France – who were founded in 1622 during the reign of Louis XIII, musketeers had already been operating across the other side of the world in China since the 14th century. Indeed, through the Ming Dynasty (1368-1644) no national army was complete without multiple musketeer divisions, with soldiers armed with matchlock muskets. Surviving texts indicate that these musketeers fired in lines and typically from a kneeling position. This development of the concept of musketeers in China stemmed from their invention and mastery of gunpowder, with the musket revolutionising traditional forms of combat.

> "The musket was deadly, albeit cumbersome to use"

© Alamy; Ian Jackson/The Art Agency

Sikorsky MH-60 Black Hawk

Designed for special operations in hostile environments, this was a new kind of war machine, built for a new kind of battlefield

From the chaotic skies over Somalia during the Battle of Mogadishu in 1993, to the covert operation to kill Osama Bin Laden in 2011, Black Hawk helicopters are among the deadliest, most effective tools available to any modern military. After its experiences in the Vietnam War in the 1960s and 70s, the US military knew just how essential it was to have tough, multi-role helicopters available. Not only were these aircraft useful for rapidly transporting combat personnel to and from battlefields, they could even remain on the front line to provide direct support. However, the existing Huey helicopters were out of date.

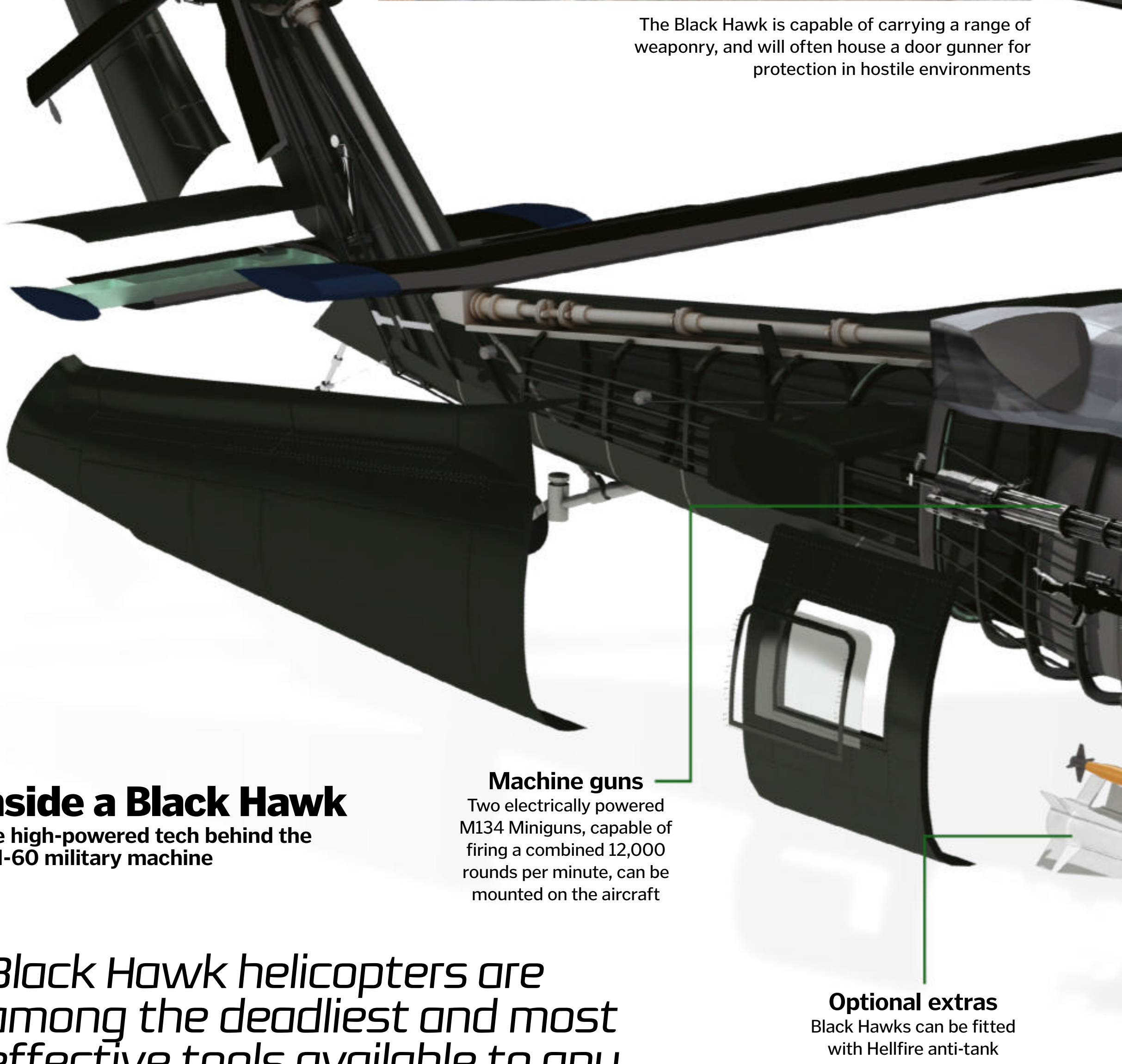
Two US companies, Boeing Vertol and Sikorsky, went head-to-head with their rival designs for the new combat helicopter, with the latter finally winning the contract with its S-70 prototype. Since the model first took to the skies in 1974, a huge number of variants have gone into production, each with its own specific role to play in a combat zone. For instance, the secretive 'MH-X' version – used during the mission to kill Al-Qaeda's chief – was rumoured to be equipped with stealth technology, making it almost undetectable to radar.

The MH-60 variant seen here was developed from the standard UH-60 Black Hawk for use during special operations. The machine's effective range was greatly increased with the addition of a more efficient fuel tank, the installation of systems for aerial refuelling, and the improvement of the craft's overall survivability. It was during a special operation that these assets would be put to the ultimate test, an incident known as Black Hawk Down.

The Black Hawk is capable of carrying a range of weaponry, and will often house a door gunner for protection in hostile environments

Inside a Black Hawk

The high-powered tech behind the MH-60 military machine



Machine guns
Two electrically powered M134 Miniguns, capable of firing a combined 12,000 rounds per minute, can be mounted on the aircraft

Optional extras
Black Hawks can be fitted with Hellfire anti-tank missiles and rocket pods, as well as additional fuel tanks for long-haul missions

> "Black Hawk helicopters are among the deadliest and most effective tools available to any modern military"

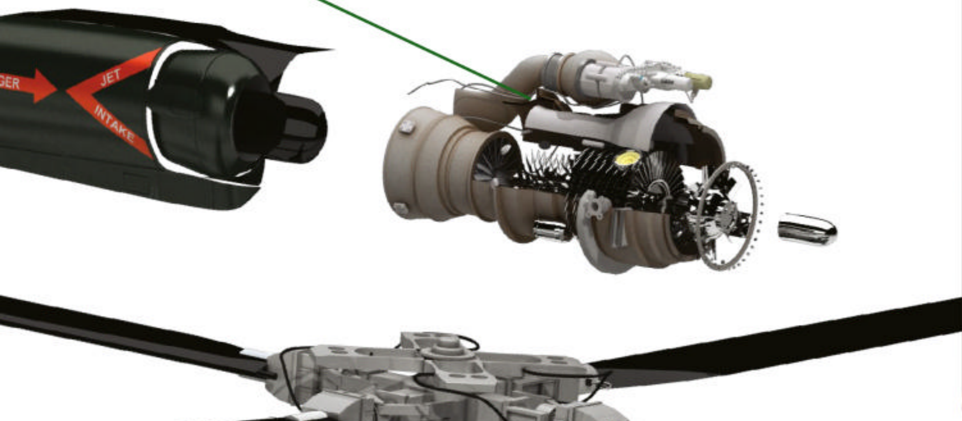
DID YOU KNOW? *The US presidential helicopter is a Black Hawk variant, the VH-60, known as White Hawk*

The Battle of Mogadishu

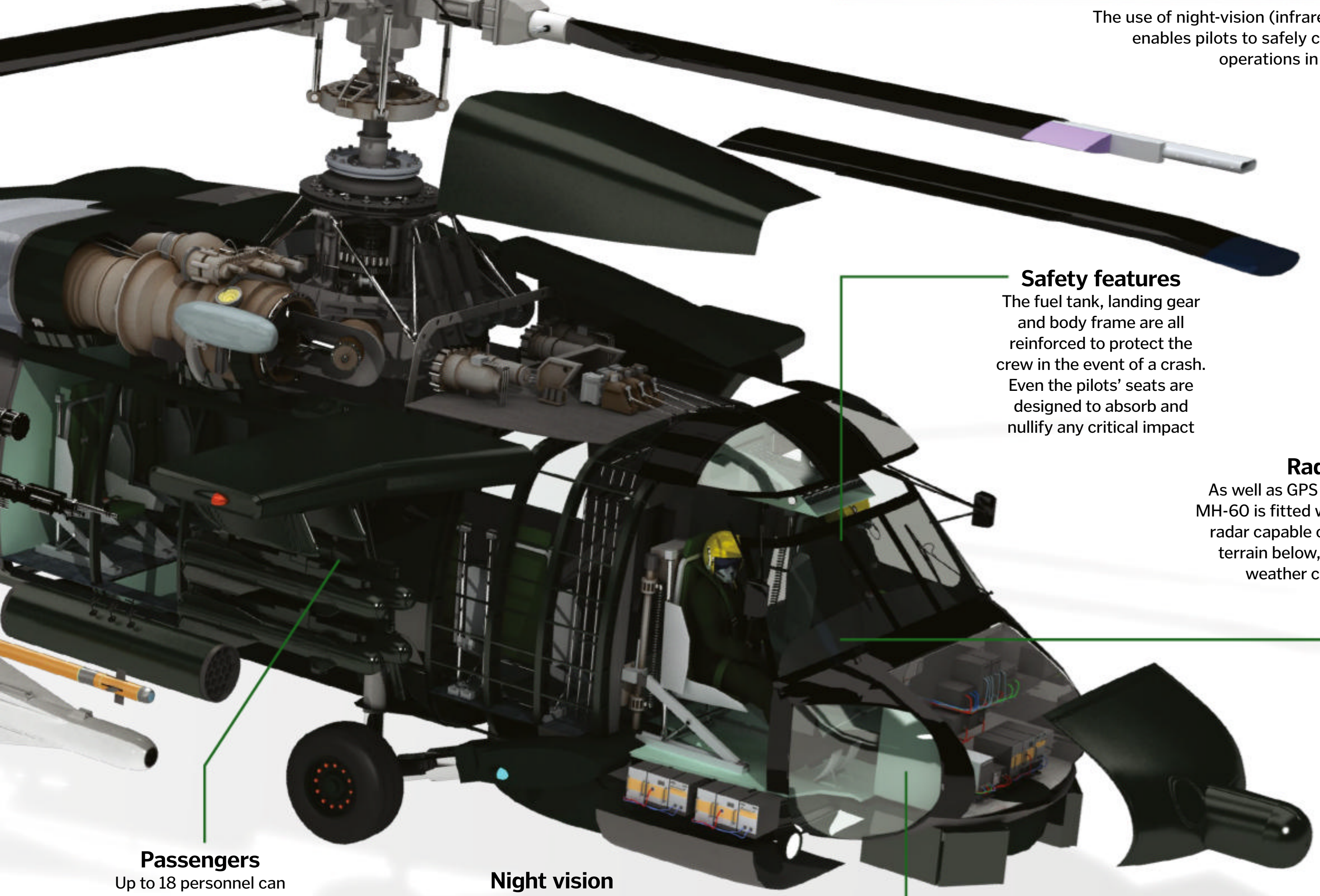
On 3 October 1993, American Rangers flew into Mogadishu, the capital of Somalia, to capture a wanted terrorist leader. They swooped down on the target's base in a convoy of helicopters, with MH-60 Black Hawks hovering overhead to provide support. However, when two of these aircraft came under fire, they crash-landed into the maze of streets and alleyways below. What was supposed to be a smooth operation soon turned into chaos as soldiers battled through the streets to reach the downed aircraft and their stricken crew. The ensuing battle is now most famously known as Black Hawk Down, due to the 1999 book of the same name, which was adapted into the 2001 Oscar-winning film.

A Black Hawk flies over Mogadishu during Operation Restore Hope, a year before the Battle of Mogadishu

Twin engines
Two General Electric engines pack a combined 3,988 shaft horsepower, enabling the aircraft to reach a top speed of 280km/h



The use of night-vision (infrared) technology enables pilots to safely conduct special operations in total darkness



Safety features
The fuel tank, landing gear and body frame are all reinforced to protect the crew in the event of a crash. Even the pilots' seats are designed to absorb and nullify any critical impact

Radar
As well as GPS capability, the MH-60 is fitted with multi-mode radar capable of tracking the terrain below, even in poor weather conditions

Passengers
Up to 18 personnel can be transported in the rear of the aircraft, which has an operational range of over 2,200km

Night vision
A forward looking infra-red (FLIR) video camera pod captures the surrounding environment and relays it to the pilot, enabling safe flight in total darkness

© Alamy; WIKI

INDUSTRY & INVENTION

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Tour some of history's most barbaric inventions

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Get to know the story behind the first ever programmable digital computer

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Unique transit systems that scale steep mountains

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Dive deep into the discoveries that changed the world

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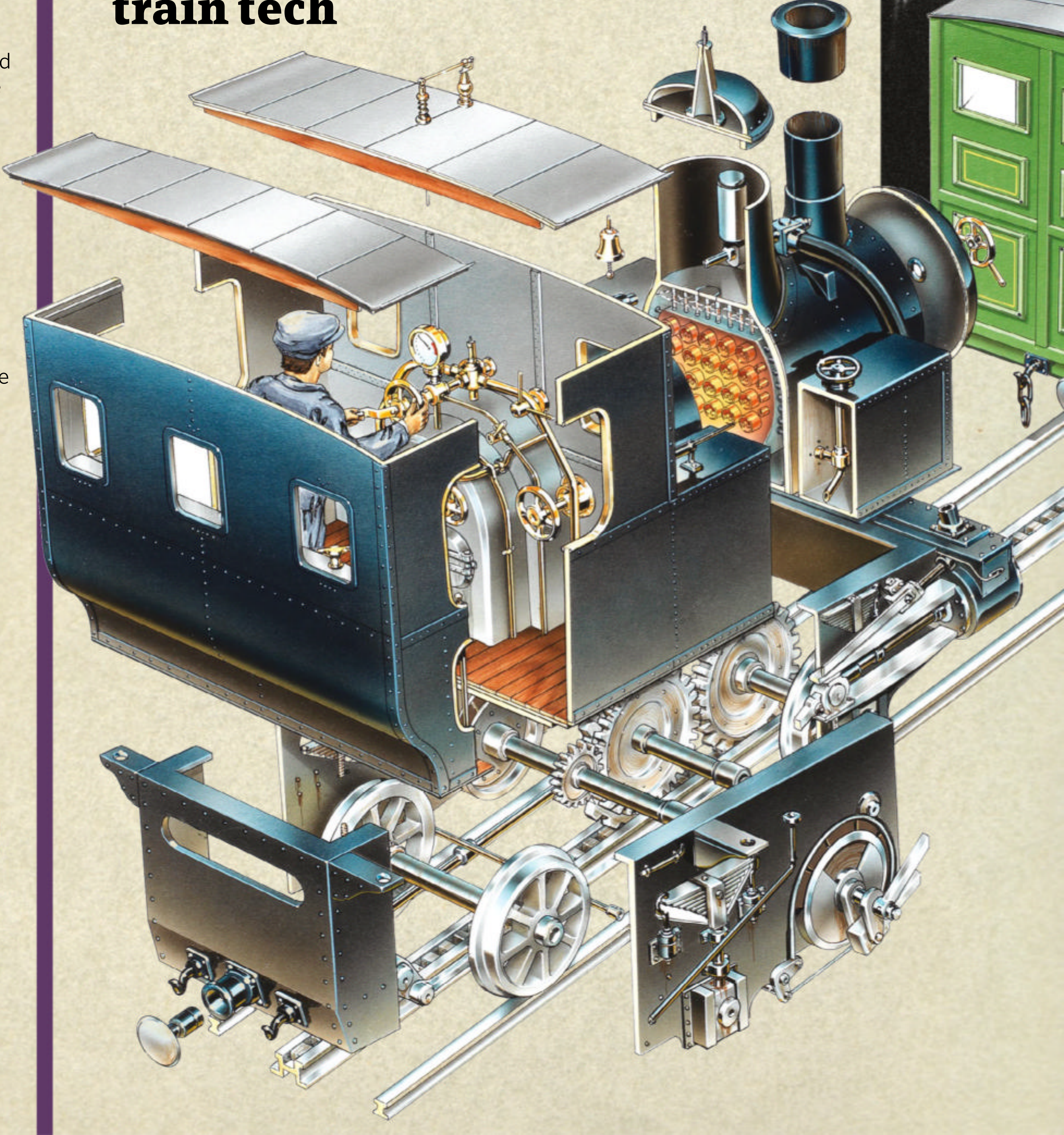
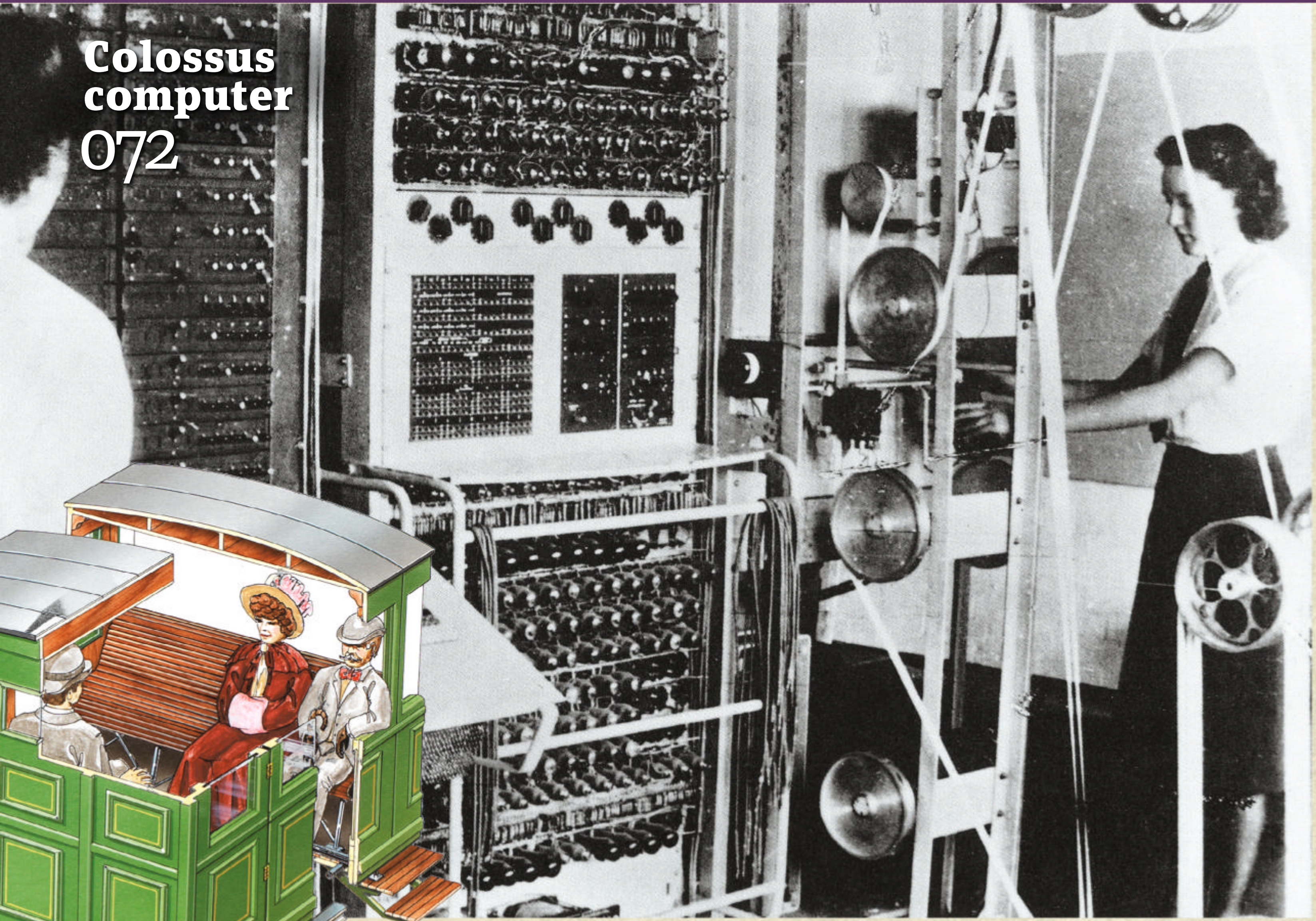
Amazing train tech



066
Gruesome inventions



Colossus computer
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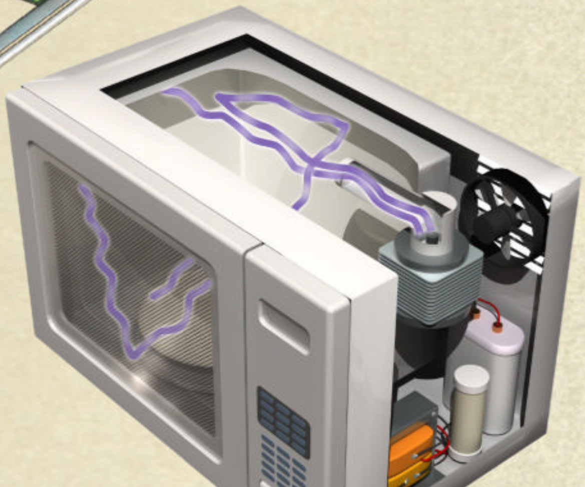

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Great accidental discoveries

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Prehistoric painting
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History's most gruesome inventions

From brutal torture devices to bizarre medical treatments, these terrifying contraptions reveal a darker side of innovation

From the wheel to the World Wide Web, we have invented some truly ground-breaking things during our time on Earth. Yet throughout history, inventors have also been known to put their skills to use in horrifying ways, creating contraptions that have caused unimaginable suffering.

In the past, if you committed a terrible crime, a punishment much worse than a long prison sentence often awaited you. From boiling people alive to sawing them in half, execution methods were often developed to be as cruel as possible. These gruesome events were usually carried out in public to deter others from committing the same crime.

But even if you weren't sentenced to death, there were plenty of ghastly implements that could be used to torture you instead. Typically used to extract a confession or information about accomplices, torture was popular in medieval times, with the screams of victims echoing from castle dungeons across Europe.

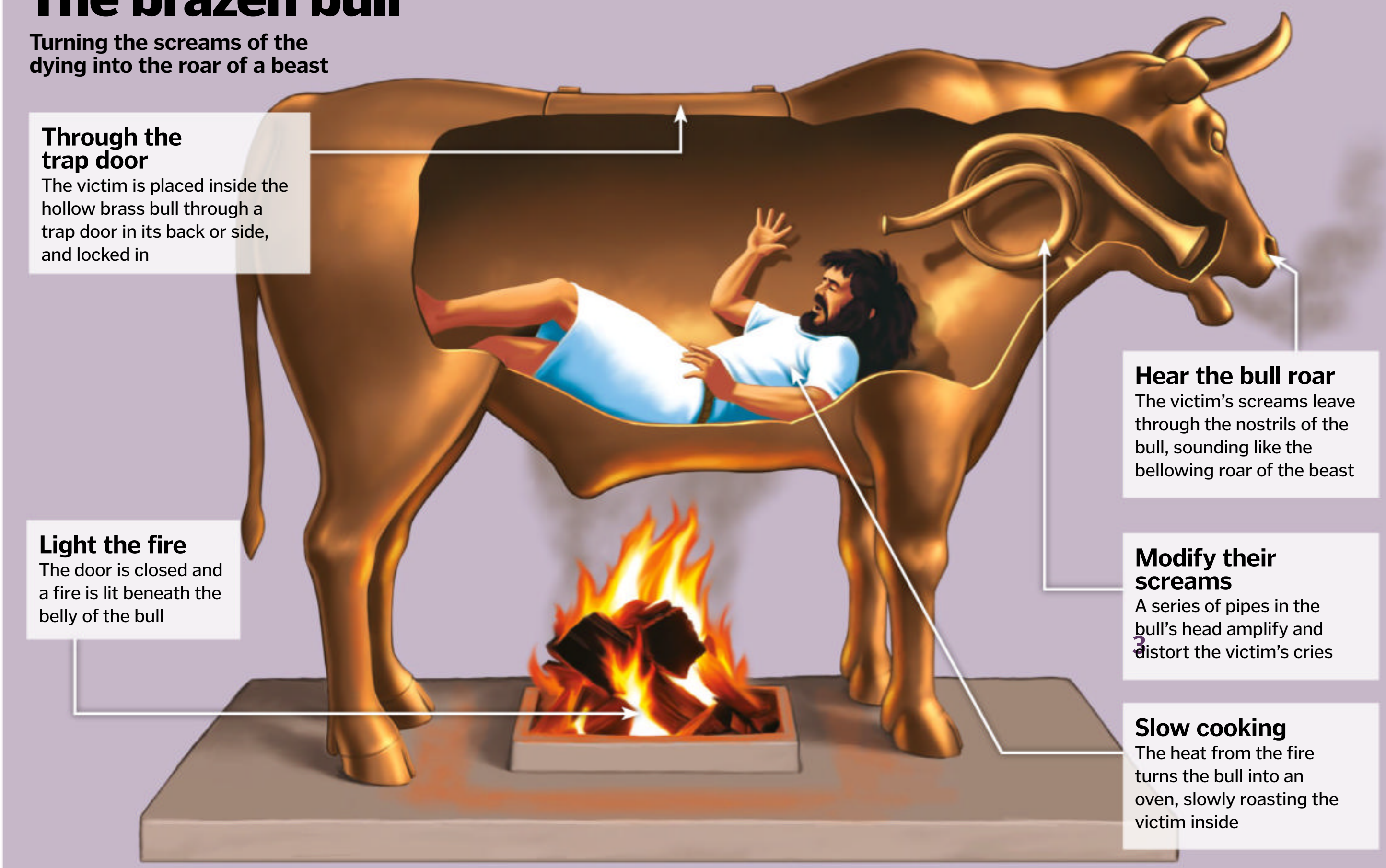
War has also inspired a selection of horrific innovations. While guns and bombs killed instantly, chemical weapons could draw out death for several agonising days – thankfully, this form of warfare is now prohibited.

We are also lucky that some medical devices from history are no longer used. Despite being designed with good intentions, many medieval procedures were truly stomach-churning, making a trip to the doctor quite the ordeal. So be grateful these inventions are before your time…

DID YOU KNOW? *Historical records showed that the brazen bull was still in use during Roman times, used by Emperor Hadrian*

The brazen bull

Turning the screams of the dying into the roar of a beast



Through the trap door
The victim is placed inside the hollow brass bull through a trap door in its back or side, and locked in

Light the fire
The door is closed and a fire is lit beneath the belly of the bull

Hear the bull roar
The victim's screams leave through the nostrils of the bull, sounding like the bellowing roar of the beast

Modify their screams
A series of pipes in the bull's head amplify and distort the victim's cries

Slow cooking
The heat from the fire turns the bull into an oven, slowly roasting the victim inside

Illustration by Tom Connell / Art Agency

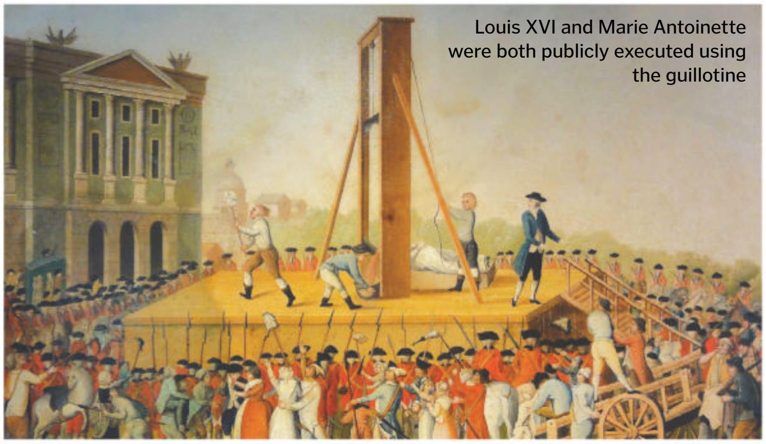
One of the most brutal methods of execution ever created took the form of a hollow bull statue. Invented in Ancient Greece by Perillus, a bronze worker in Athens, it was given as a gift to a cruel tyrant named Phalaris of Agrigentum. As well as roasting criminals alive, the device doubled as a musical instrument, converting the victim's desperate cries into what Perillus described as "the tenderest, most pathetic, most melodious of bellowings". Distrustful of the inventor's claims, Phalaris ordered Perillus to climb inside and prove the device's musical capabilities. As soon as he was inside, Phalaris shut the door and lit a fire beneath. However, rather then letting him die at the hands of his own creation, Phalaris had him removed and thrown off a cliff instead.

© Corbis; Look & Learn

Crucifixion

Devised over 2,500 years ago as punishment for the most serious crimes, crucifixion would kill victims in a horribly drawn-out and painful way. With their wrists and feet nailed or tightly bound to a cross, and their legs broken by the executioners to speed up death, the victim's weight would be transferred to their arms. This would gradually pull the shoulders and elbows out of their sockets, leaving the chest to bear the weight. Although inhaling would still be possible, exhaling would be difficult and the victim would eventually suffocate due to a lack of oxygen. This excruciating process could take 24 hours.

Crucifixion would lead to suffocation and multiple organ failure



Louis XVI and Marie Antoinette were both publicly executed using the guillotine

Guillotine

Although beheading methods had already been around for centuries, in 1789 French physician Dr Joseph Guillotin proposed a much more efficient and humane device for decapitation. When the executioner released the rope holding the guillotine's weighted blade in place, it would drop onto the victim's neck, killing them in a fraction of a second. This helped to eliminate the human error that was common with axe and sword beheadings, sometimes requiring multiple swings to fully remove the head. Although quick, guillotine executions were popular spectator events during the French Revolution and the guillotine operators became national celebrities.

Electric chair

Electrocution was adopted as a quicker and supposedly less painful method of execution than hanging in the 1880s. The victim has their head and one calf shaved to reduce resistance to electricity before being strapped in across their waist, arms and legs. A moistened sponge is placed on their head and an electrode in the shape of a metal skullcap is secured on top. Another electrode is attached to their shaved leg before the power is switched on. 2,000 volts pass through their body, paralysing the respiratory system and causing cardiac arrest.

Electrocution is still used as a method of execution in some US states

Inside a torture chamber

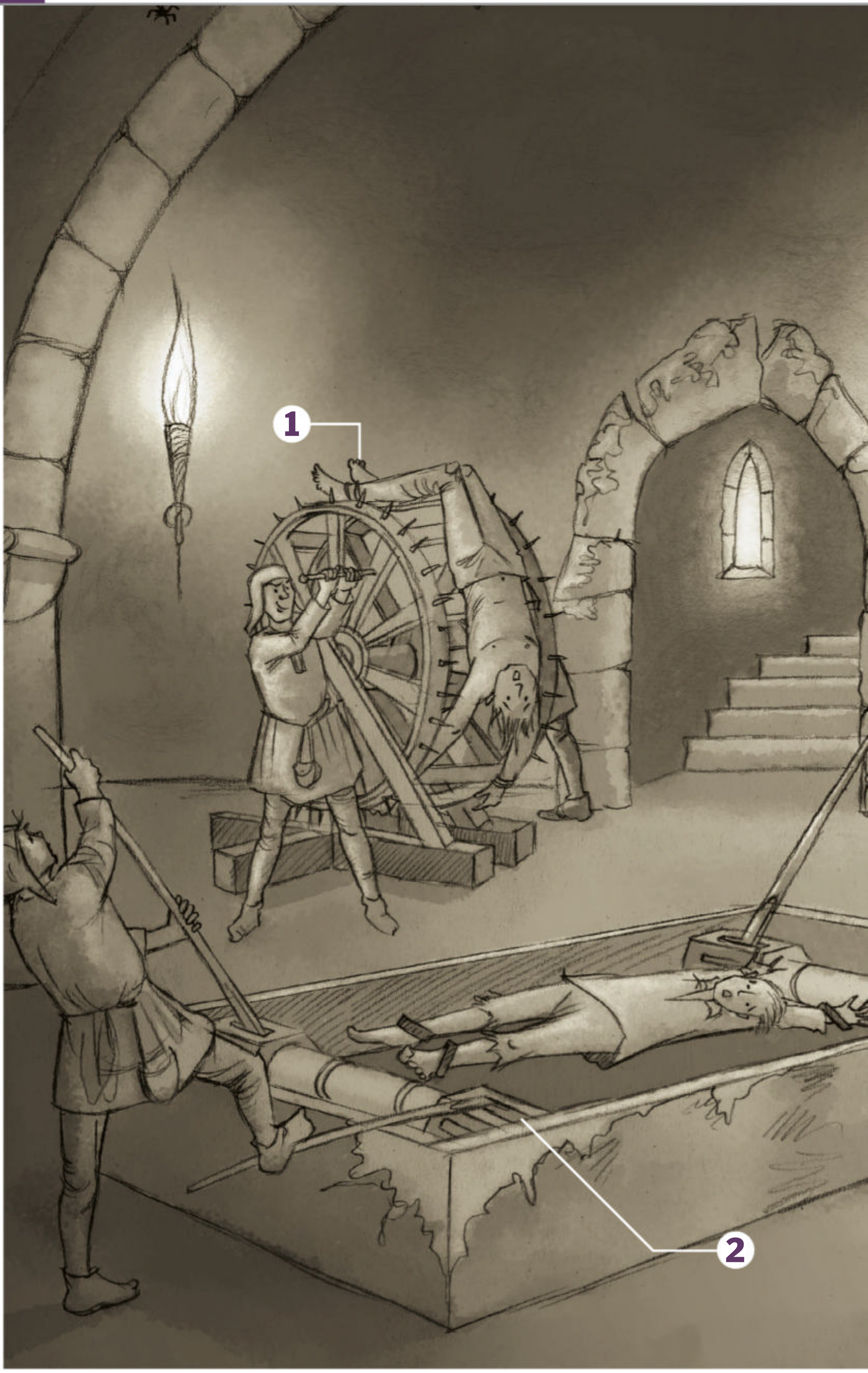
The terrifying devices that inflicted intense pain

Torture has been used as a method of punishment and interrogation for centuries, with the Ancient Greeks and Romans regularly torturing criminals as part of their justice system. However, by the Middle Ages torture had become particularly prevalent, especially in response to crimes of treason. If you had been disloyal to the sovereign and your country, a whole plethora of horrifying torture devices awaited you.

Torture was usually conducted in secret, with most medieval castles featuring an underground dungeon in which these diabolical deeds took place. A great deal of ingenuity and artistic skill went into developing instruments that would inflict the maximum amount of pain. Often simply threatening to use one on a person was enough to get them to confess, while others would quickly give in after seeing it used on a fellow prisoner. Some torture devices were designed to only inflict pain, but others would result in a slow, drawn-out death that prolonged suffering until the victim drew their last breath.

> *"Often simply threatening to use torture on a person was enough to get them to confess"*

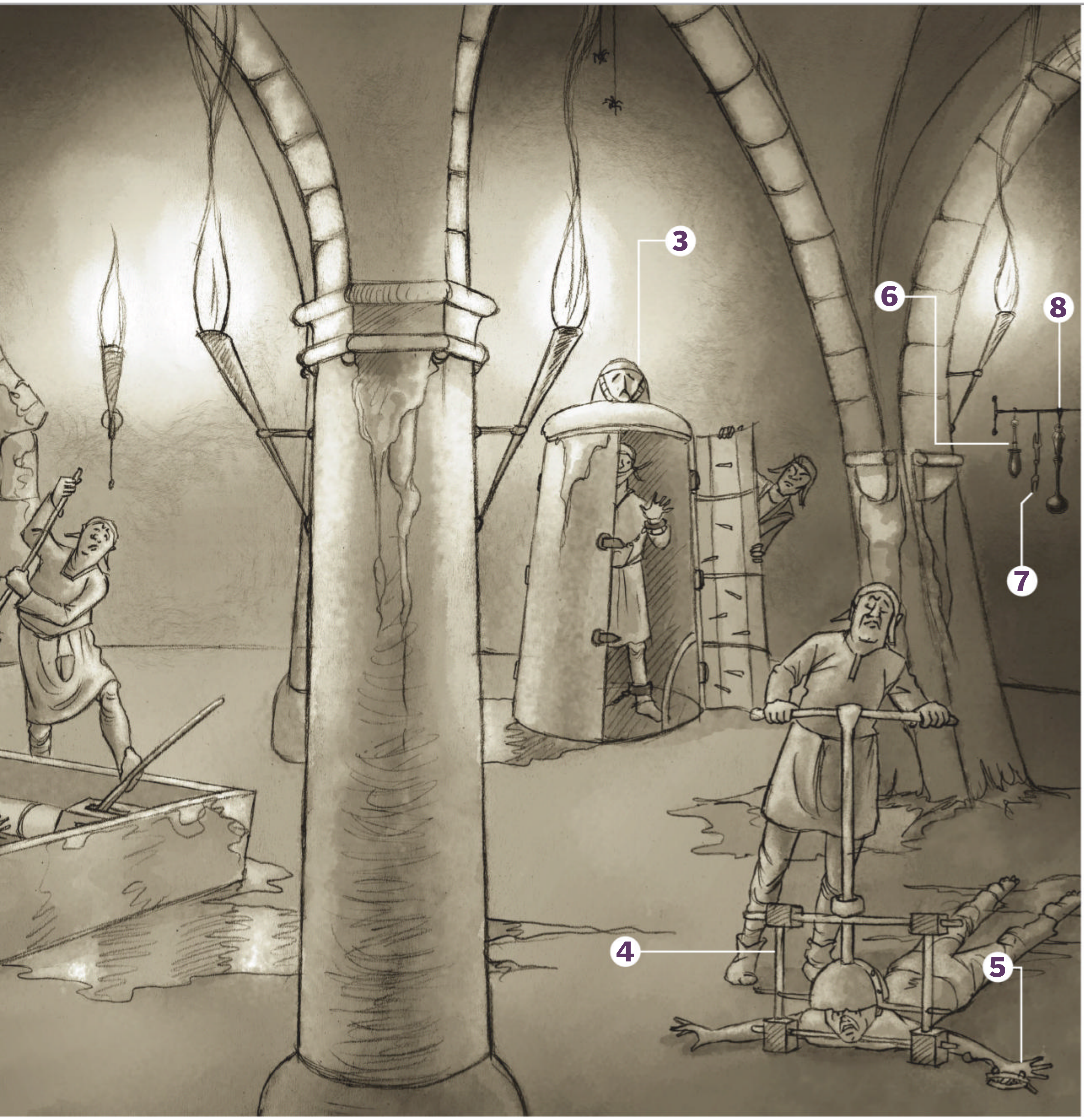
However, even if a prisoner was lucky enough to survive the torture, they were usually left severely disfigured and often had to be to be carried to their resulting trial as they could no longer walk on their own. From the mid-17th century onwards, torture became much less common as there was much speculation about its effectiveness. Many prisoners would say anything to end their suffering, so it often produced inaccurate information or false confessions. It wasn't until 1948 that the United Nations General Assembly adopted the Universal Declaration of Human Rights, banning the use of torture.



1 Breaking wheel
With the victim's limbs tied to the spokes of this large wooden wheel, it would be slowly revolved. As it spun, the executioner would bludgeon the victim's arms and legs with an iron hammer, shattering their bones one by one. If the victim survived this, they were placed on top of a large pole so birds could peck at their body until they eventually died of dehydration, which could take several days.

2 The rack
With their hands and feet tied to rollers at each end of the wooden frame, the victim would be subjected to brutal interrogation. If they failed to confess or give up the information the torturer was looking for, a crank would be turned to rotate the rollers. This would pull on the ropes, gradually and painfully stretching the victim's body, eventually dislocating their limbs.

3 Iron maiden
A series of menacing spikes protruded from the interior of this iron chamber. With the victim inside, the door was closed slowly, causing the strategically placed spikes to pierce the body. However, the spikes were not long enough to be instantly fatal. Instead, the victim would be left to slowly bleed to death.



4 Head crusher
With the victim's chin placed over the bottom bar and their head beneath the metal cap, the executioner would slowly turn the screw to bring the two together, only stopping if the victim gave the right answers. As the victim's head was crushed, their teeth would shatter into their jaw and their eyes would pop out from their sockets.

5 Thumb-screws
Used as punishment or a method of extracting information, the victim's fingers, thumbs or toes were placed between two horizontal metal bars. When the screw was turned, the two bars were pressed together, crushing the digits inside. Some thumbscrews even featured metal spikes on the bars to increase the pain.

6 Choke pear
Also known as the 'pear of anguish', this device was inserted into one of the victim's orifices, such as their mouth. When the key or crank was turned, the 'petals' of the pear-shaped end would slowly open up, painfully mutilating the victim's insides, but not causing death.

7 Heretic's fork
Usually reserved for blasphemers, this metal rod with two prongs at either end was attached to a leather strap around the victim's neck. One end would pierce their chin, while the other dug into their sternum, causing immense pain if they attempted to move their jaw or neck, making it more or less impossible to talk.

8 Lead sprinkler
Deceptively designed to look like a holy water sprinkler, this device was actually filled with molten lead, acid or boiling hot oil or water. The long handle was shaken to shower the victim's body with the substance inside. This caused horrific burns and was potentially lethal.

Miserable medicine

The medical practices that did more harm than good

Nowadays, when you're feeling unwell, you can visit a clean hospital and receive tried-and tested-treatments from a doctor with years of medical training. We often take this modern medicine for granted, but our ancestors throughout history were not quite so lucky when it came to health care. In medieval England for example, poor hygiene and filthy living conditions meant that disease was very common.

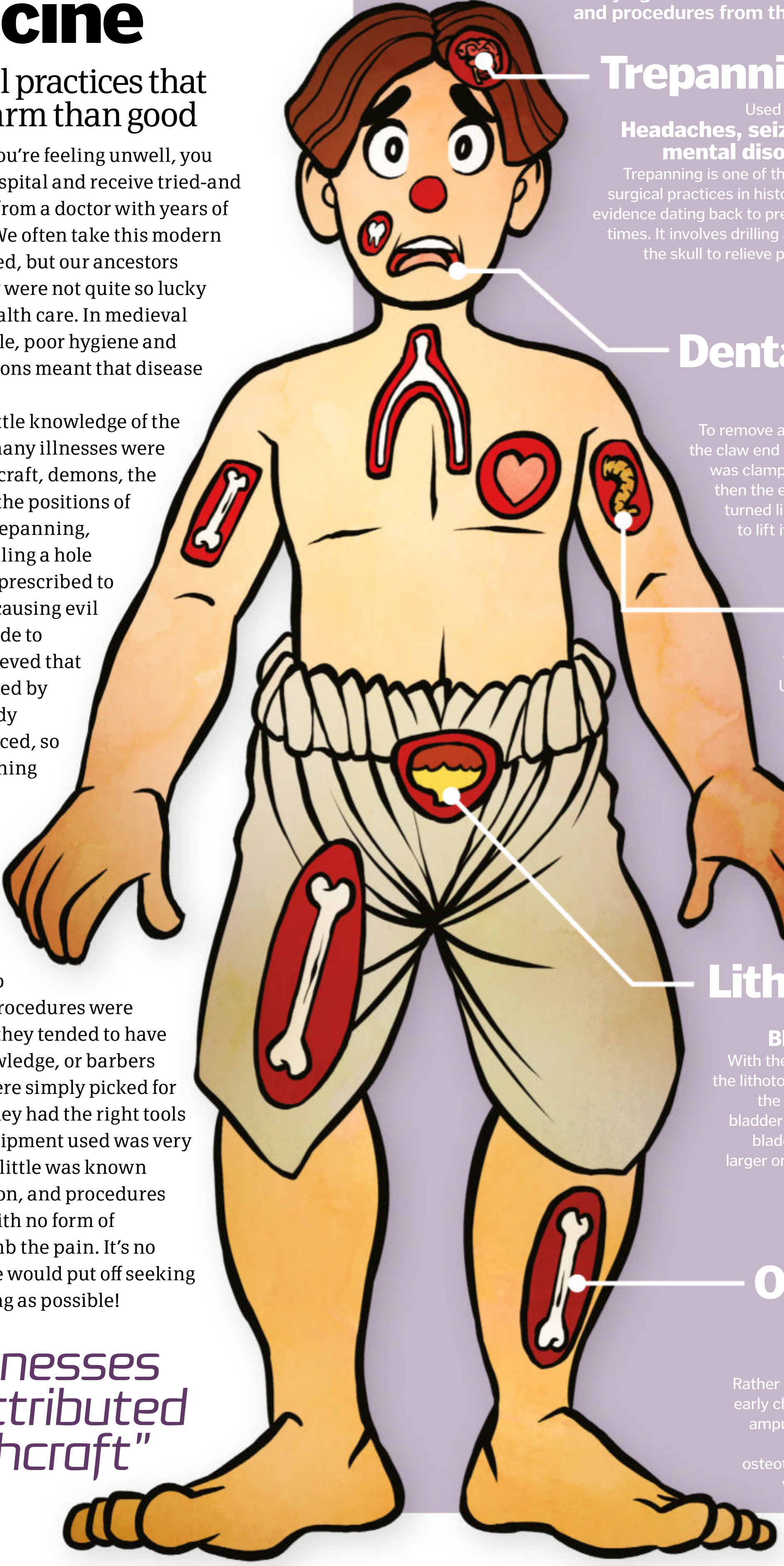
However, with little knowledge of the human anatomy, many illnesses were attributed to witchcraft, demons, the will of god or even the positions of celestial bodies. Trepanning, which involves drilling a hole into the skull, was prescribed to allow the disease-causing evil spirits trapped inside to escape. Others believed that diseases were caused by the fluids in the body becoming unbalanced, so bloodletting – draining the blood from a particular part of the body – was thought to restore that balance to normal levels.

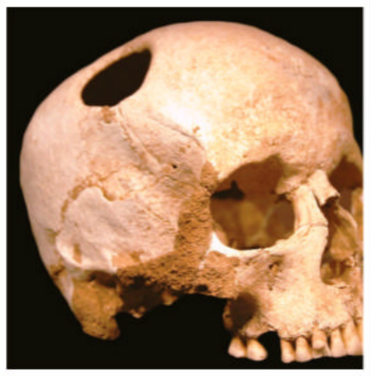
The 'doctors' who carried out these procedures were usually monks, as they tended to have basic medical knowledge, or barbers or butchers who were simply picked for the task because they had the right tools for the job. The equipment used was very rarely sterilised as little was known about contamination, and procedures were carried out with no form of anaesthesia to numb the pain. It's no wonder that people would put off seeking treatment for as long as possible!

> *"Many illnesses were attributed to witchcraft"*

Terrifying treatments

Horrifying medical instruments and procedures from the past



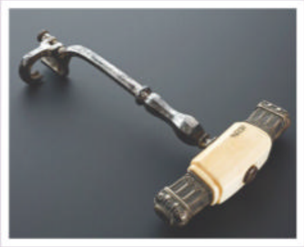


Trepanning

Used to treat:

Headaches, seizures, mental disorders

Trepanning is one of the oldest surgical practices in history, with evidence dating back to prehistoric times. It involves drilling a hole in the skull to relieve pressure.



Dental key

Used to treat:

Toothache

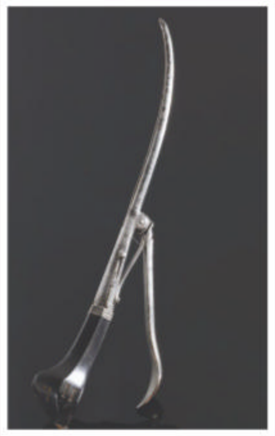
To remove a damaged tooth, the claw end of the dental key was clamped around it and then the entire device was turned like a key in a lock to lift it out of the gum.

Artificial leech

Used to treat:

Various infections and diseases

Used for bloodletting, a popular treatment for a wide range of medical conditions, this device mimicked the action of reel leeches, with rotating blades that cut into the skin while a vacuum in the cylinder sucked out the blood.

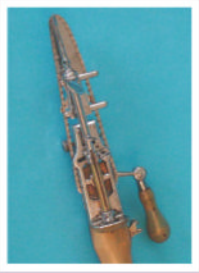


Lithotome

Used to treat:

Bladder stones

With the patient still awake, the lithotome was inserted up the urethra and into the bladder to grip onto smaller bladder stones or cut up larger ones so they could be passed naturally.



Osteotome

Used to treat:

Infections in the arms or legs

Rather then cutting down trees, this early chainsaw was actually used to amputate limbs. Unlike a hammer and chisel, the hand-cranked osteotome could cut through bone without causing it to splinter.

DID YOU KNOW? *World War I soldiers described the smell of chlorine gas as a combination of pepper and pineapple*

Weapons of war

The chemical arms race changed warfare forever

Chemical weapons

On 22 April 1915, Germany shocked the world by launching the first large-scale gas attack in war. After waiting several weeks for the wind to blow in the right direction, German soldiers released clouds of chlorine gas near the enemy trenches in Ypres, suffocating the unprepared Allied troops. Although The Hague Convention of 1899 prohibited the use of poisonous weapons, Germany justified its actions by claiming that France had already broken the ban by deploying tear gas grenades in 1914. The chlorine gas attack kick-started a chemical arms race, and by the end of World War I around 50 different chemicals had been used on the battlefield. The most prevalent were chlorine, phosgene and mustard gas, which would result in slow and painful deaths if soldiers were exposed to large enough quantities. Eventually, gas masks were developed for protection, but chemicals such as mustard gas could still cause horrific blisters if they came into contact with the skin. Among the most devastating chemical weapons are nerve agents, such as sarin, which attack the nervous system. Even small concentrations can be lethal, killing in mere minutes.

Cl_2

Chlorine

Appearing as a pale green cloud with a strong bleach-like odour, chlorine gas reacts with water in the lungs to form hydrochloric acid. This damages the lung tissue, causing coughing, vomiting and eventually death.

$COCl_2$

Phosgene

This colourless gas with a musty odour reacts with proteins in the alveoli, tiny air sacs found in the lungs. This leads to fluid in the lungs and eventually suffocation, but the symptoms can take up to 48 hours to manifest.

$C_4H_8Cl_2S$

Mustard gas

With the odour of garlic, horseradish or sulphur, yellow-brown clouds of mustard gas cause chemical burns on the skin, eyes and respiratory tract, leading to large blisters, temporary blindness and shortness of breath.

$C_4H_{10}FO_2P$

Sarin

Colourless, tasteless and odourless, this gas blocks normal communication between nerves. The nerve signals become stuck 'on', and muscles are unable to relax. This can lead to spasms, paralysis and asphyxiation.

The Geneva Protocol

By the end of World War I, over 125,000 tons of poison gas had been deployed in battle. Although it was only responsible for less than one per cent of the war's total fatalities, the psychological terror it had inflicted on soldiers was immense. On 17 June 1925, seven years after the war had ended, the Geneva Protocol was introduced, prohibiting the use of chemical and biological weapons. 138 states have now signed the treaty.

38 states originally signed the Geneva Protocol to ban the use of chemical weapons

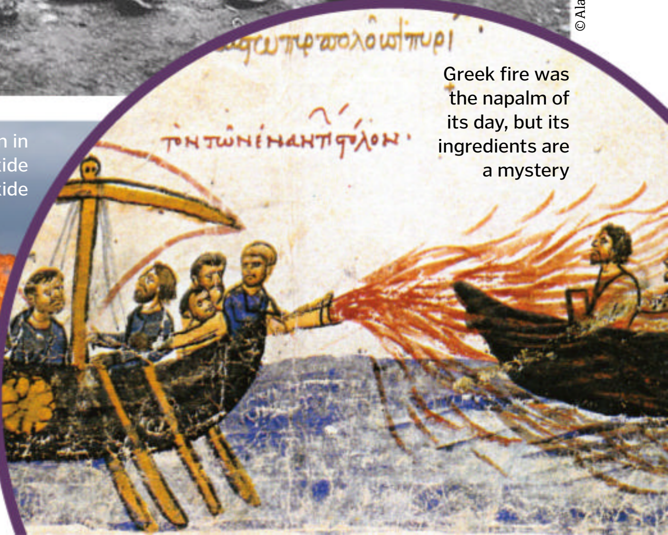
Napalm

Napalm is a flammable liquid with a gel-like consistency, allowing it to stick to surfaces easily. In a bomb, it is combined with gasoline or jet fuel to explode upon impact, burning at over 2,760 degrees Celsius. Contact with skin can result in severe burns and even death by asphyxiation. When ignited, napalm generates carbon monoxide and removes oxygen from the air, suffocating those in the vicinity. Some of the greatest atrocities of war were caused by napalm.

Greek fire

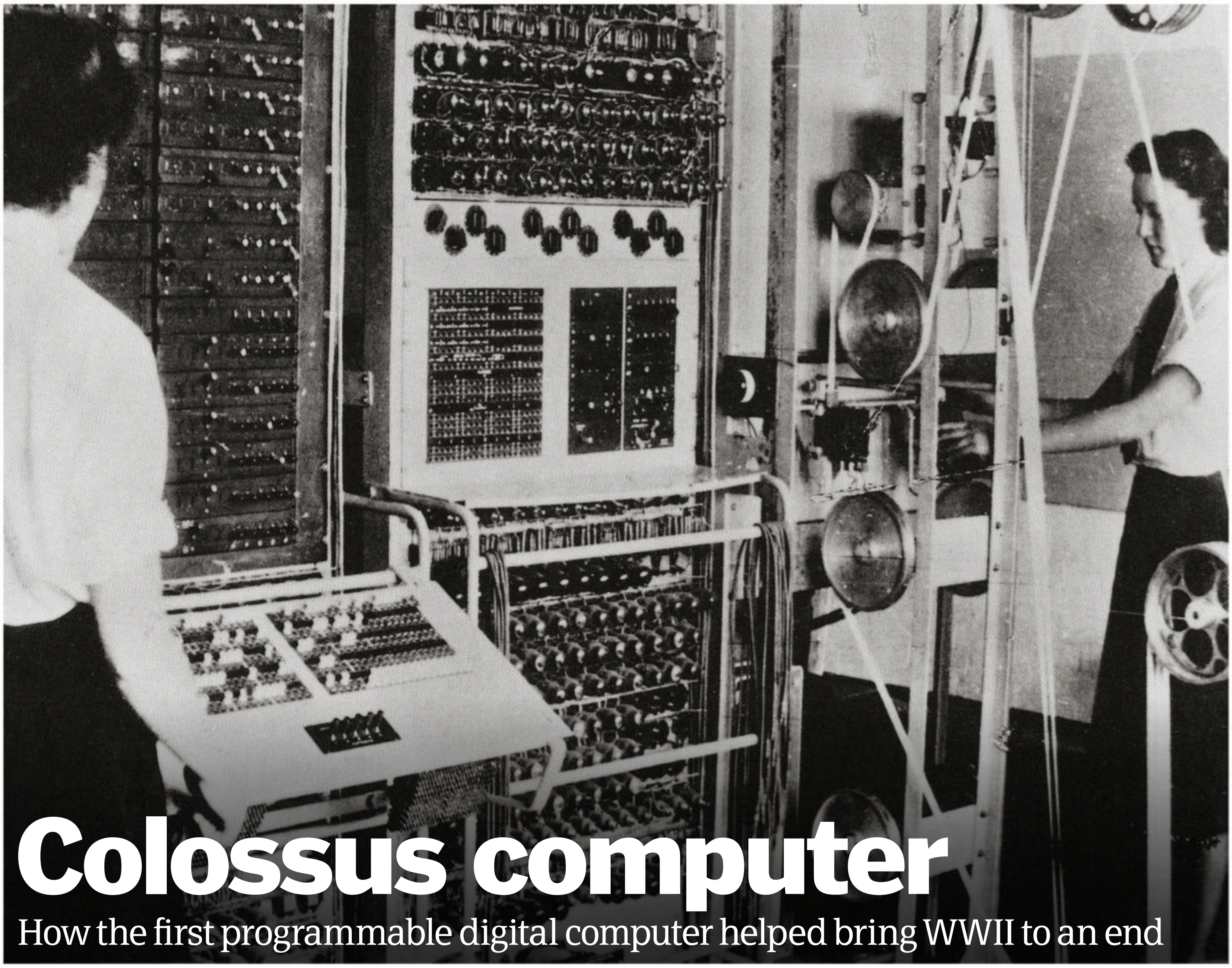
Developed by the Byzantine Greeks in the 7th century, Greek fire was a flammable liquid that could burn on water, making it particularly effective for naval warfare. It was sprayed at the enemy using early flamethrower devices, or thrown in primitive hand grenades. The resulting fire could only be extinguished with sand, vinegar or urine. The true ingredients are a mystery, but scientists believe it could have contained petroleum, sulphur and pine tar.

Napalm fires combust oxygen in the air, turning carbon dioxide into carbon monoxide



Greek fire was the napalm of its day, but its ingredients are a mystery

© Alamy;SPL; WIKI; Dreamstime



Colossus computer

How the first programmable digital computer helped bring WWII to an end

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and the keystream established.

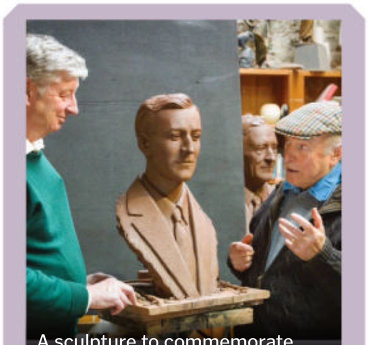
Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A colossal reconstruction

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after WWII, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus's optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.

DID YOU KNOW? *The Colossus was not made public knowledge until the 1970s due to the Official Secrets Act*



A sculpture to commemorate Flowers, with his son (left)

Flowers in focus

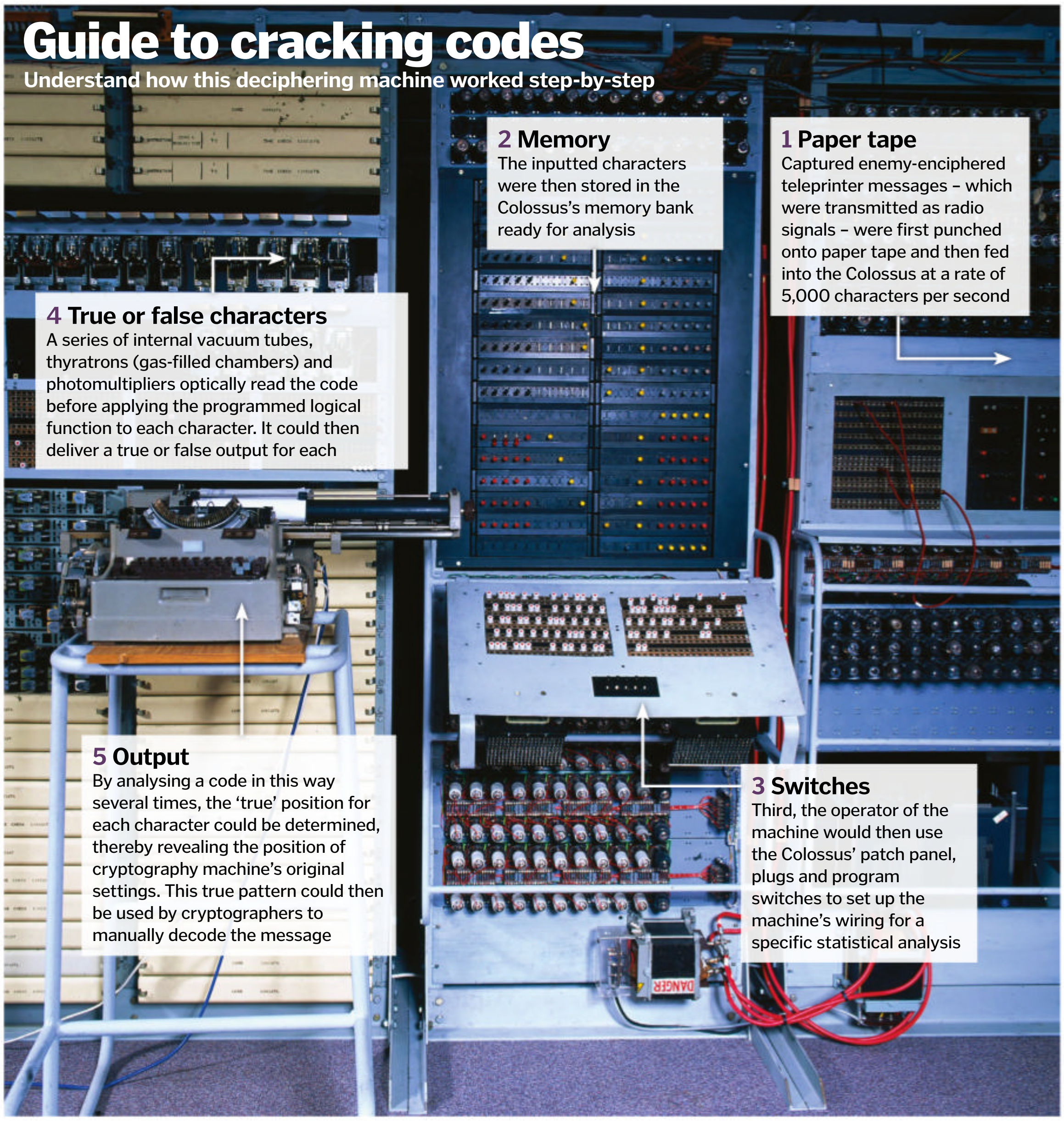
Thomas (Tommy) Flowers was the British engineer behind the revolutionary design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades after the war as he was sworn to secrecy.

Guide to cracking codes

Understand how this deciphering machine worked step-by-step



1 Paper tape
Captured enemy-enciphered teleprinter messages – which were transmitted as radio signals – were first punched onto paper tape and then fed into the Colossus at a rate of 5,000 characters per second

2 Memory
The inputted characters were then stored in the Colossus's memory bank ready for analysis

3 Switches
Third, the operator of the machine would then use the Colossus' patch panel, plugs and program switches to set up the machine's wiring for a specific statistical analysis

4 True or false characters
A series of internal vacuum tubes, thyratrons (gas-filled chambers) and photomultipliers optically read the code before applying the programmed logical function to each character. It could then deliver a true or false output for each

5 Output
By analysing a code in this way several times, the 'true' position for each character could be determined, thereby revealing the position of cryptography machine's original settings. This true pattern could then be used by cryptographers to manually decode the message

In 1993 Bletchley Park was re-opened as a museum devoted to code breakers

Bletchley's role in WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes, Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communiqués.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes – as discussed in more detail in 'A colossal reconstruction' opposite.

After WWII Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

> *"Bletchley Park was the main decryption headquarters throughout World War II"*

© Getty; Alamy; BT

Rack-and-pinion railways

How did these unique transit systems help hefty locomotives scale steeper mountain slopes than ever before?

A rack-and-pinion railway (also known as a cog railway) was one that employed a toothed track. The addition of the toothed rail – which was usually located centrally between the two running rails – enabled locomotives to traverse steep gradients over 7 per cent, which remains to this day the maximum limit for standard adhesion-based railways.

Core to the operation of each rack-and-pinion system was the engagement of the locomotive's circular gears onto the linear rack. The rack and pinion therefore was essentially a means of converting the rotational energy generated by the train's powerplant into linear motion on the rack. As both the rack-and-pinion gears had teeth, the system also acted as an additional form of adhesion to the track, with the inter-meshing teeth holding the vehicle in place when not in motion.

Due to the primary form of power traditionally being steam, for rack-and-pinion systems to work the trains needed to be considerably adjusted. This modification stretched from the undercarriage of the train (so pinions could be installed) to the tilting of its boiler, cab and superstructure.

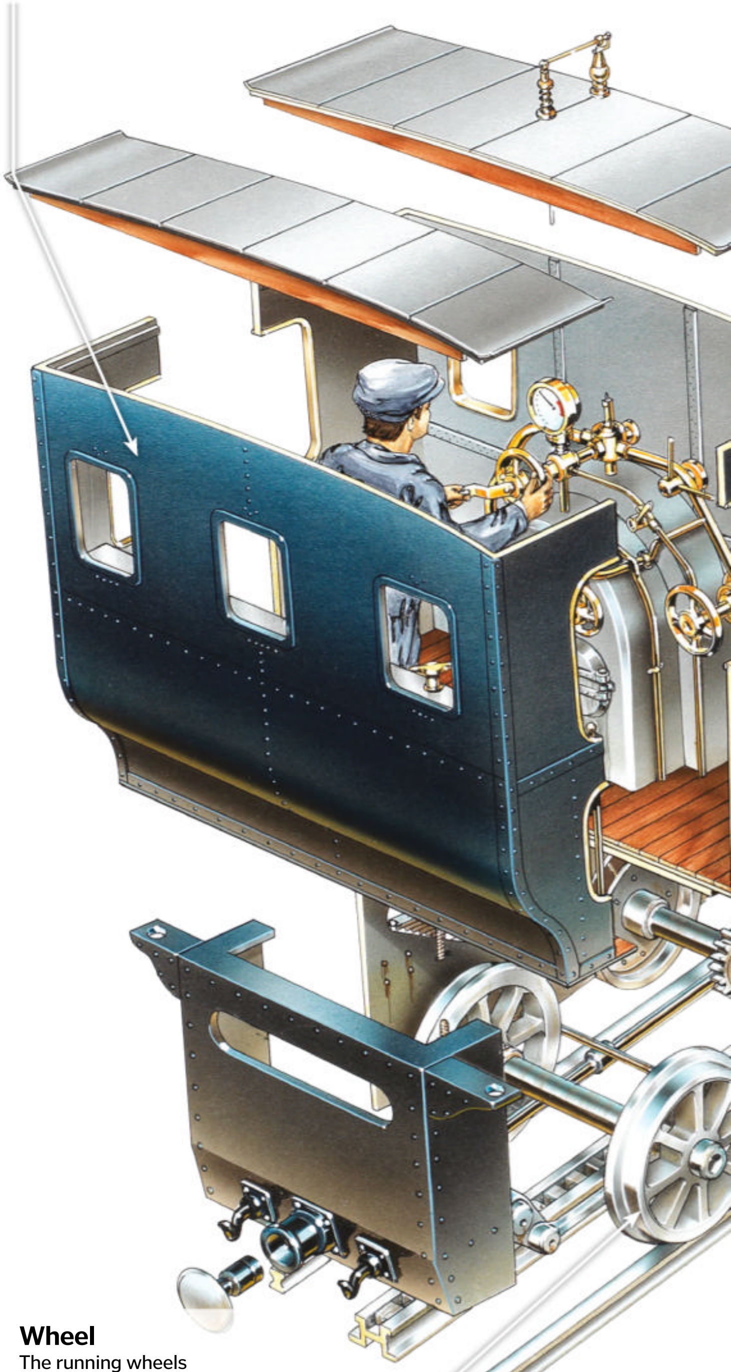
Tilting was necessary as steam engine boilers require water to cover the boiler tubes and firebox at all times to maintain stability – something that is nigh-on impossible to achieve if the train isn't level. As such, cog railway locomotives would lean in towards the track to counter the terrain's gradient.

Today, while rare, rack-and-pinion systems are still in operation worldwide, albeit with a mix of steam engines and diesel/electric locomotives. One of the most famous is the Mount Washington Cog Railway, which we look at more closely in the boxout opposite.

A rack-and-pinion railway built with a Strub system in rural Italy, 1920

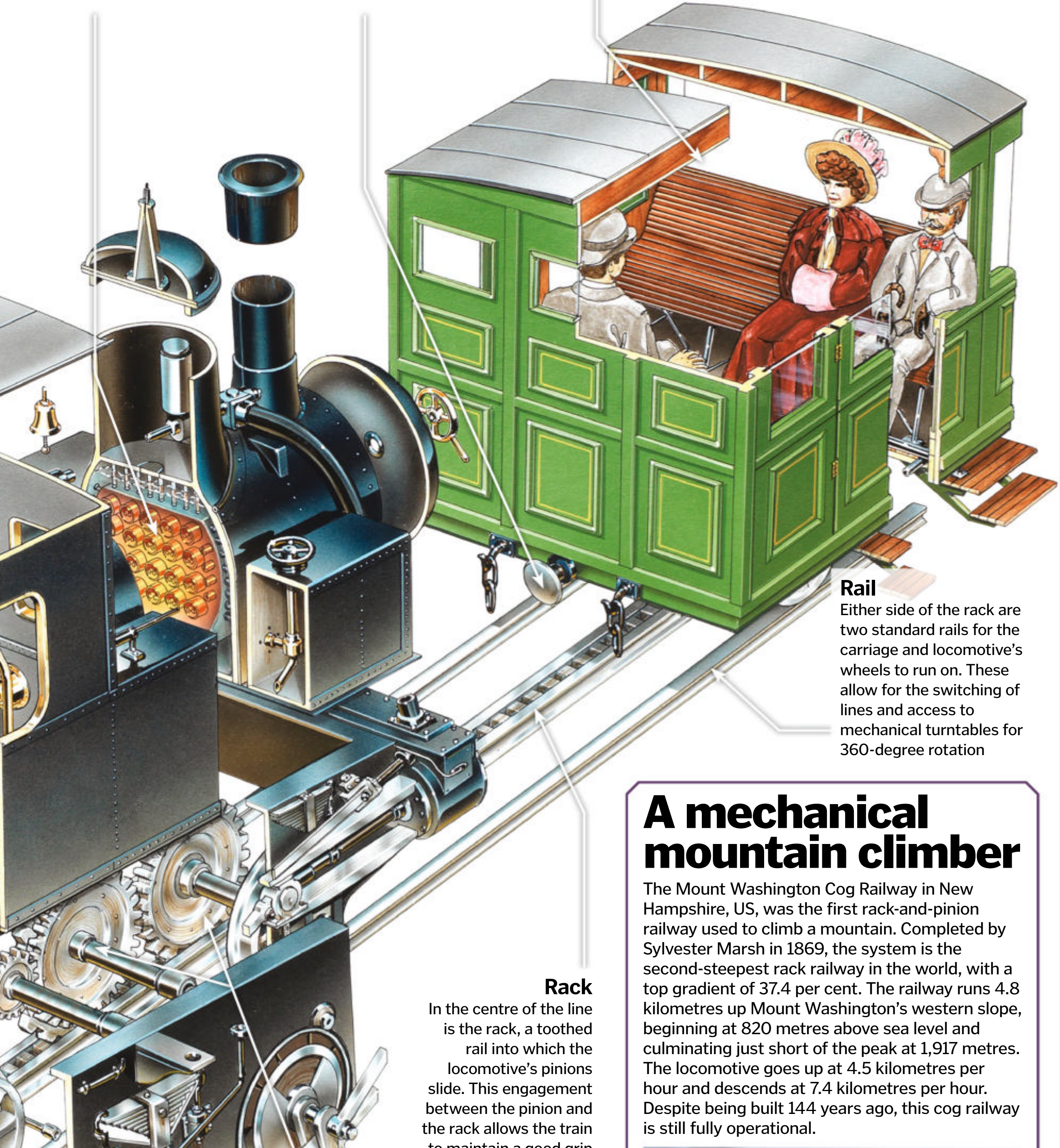
Rack and roll

Understand the anatomy of a rack-and-pinion locomotive now with our cutaway illustration



Cabin
To the rear of the engine and carriage is the cabin. From here the driver controls the steam boiler and the engagement of the pinion gears

Wheel
The running wheels work like standard train wheels, running along the rails either side of the central rack



Engine
Older cog railways would use steam engines to provide the power to drive the pinion gears. As with the cab, the engine is tilted forward so it's level during operation

Buffer
Unlike standard adhesion trains, rack-and-pinion systems don't tend to attach the carriage to the locomotive with a linkage. Instead, the carriage is simply pushed with the locomotive's buffers

Carriage
Passengers sit in a covered wooden carriage. Due to the slow nature of the system, larger-than-standard windows are often installed that offer panoramic views

Rail
Either side of the rack are two standard rails for the carriage and locomotive's wheels to run on. These allow for the switching of lines and access to mechanical turntables for 360-degree rotation

Rack
In the centre of the line is the rack, a toothed rail into which the locomotive's pinions slide. This engagement between the pinion and the rack allows the train to maintain a good grip even on steep terrain

Pinion gears
Mounted to the locomotive's undercarriage is a series of circular, teethed gears. As these rotate, driven by the engine, the teeth slot into the recesses in the rack, helping haul the train along.

A mechanical mountain climber

The Mount Washington Cog Railway in New Hampshire, US, was the first rack-and-pinion railway used to climb a mountain. Completed by Sylvester Marsh in 1869, the system is the second-steepest rack railway in the world, with a top gradient of 37.4 per cent. The railway runs 4.8 kilometres up Mount Washington's western slope, beginning at 820 metres above sea level and culminating just short of the peak at 1,917 metres. The locomotive goes up at 4.5 kilometres per hour and descends at 7.4 kilometres per hour. Despite being built 144 years ago, this cog railway is still fully operational.

Cog railway evolution

1 Marsh

Made famous by the Mount Washington Cog Railway, the Marsh system – invented by Sylvester Marsh in 1861 – used the locomotive's gear teeth like rollers, arranged in rungs between two 'L'-shaped wrought-iron rails.

2 Riggenbach

The 1863-made system created by inventor Niklaus Riggenbach used a ladder rack made from steel plates connected by regularly spaced rods. While effective, the fixed ladder rack was fairly complicated and expensive to build, so very few examples survive.

3 Abt

Carl Roman Abt improved the Riggenbach system in 1882 by using multiple solid bars with vertical teeth machined into them that were mounted centrally between the rails. This ensured the pinions on the wheels were in constant contact with the rack.

4 Locher

Eduard Locher's system designed in 1889 had gear teeth cut into the sides of the rails rather than the top, which were engaged by two cog wheels on the locomotive. This new system could work on steeper track gradients than anything prior.

5 Strub

Invented by Emil Strub in 1896, the Strub system utilised a rolled flat-bottom rail with rack teeth machined into the head 100mm (4in) apart. The safety jaws installed on the locomotive gripped the underside of the head in order to prevent dangerous derailments.

© Alamy; Thinkstock

EUREKA!

10 accidental discoveries that changed the world

It's no secret that the best ideas often come to us when we least expect them to. For some it may be on the drive home from work or in the middle of the night, while others may have their lightbulb moments while taking 'time out' in the bathroom. The ancient Greek mathematician Archimedes was in the latter group, having famously realised how to measure the volume of irregular objects while taking a bath. When he climbed in, the water level rose, and it occurred to him that the volume of water displaced must be equal to his own. How he maintained his reputation after running naked through the streets screaming 'Eureka', we're not sure!

It's not just ideas that can come to us by chance; sometimes it's a physical invention. While it's true that most of history's greatest discoveries were made after years of painstaking research, others happened completely by accident. Take the humble ice lolly, for example. Arguably a lifesaving invention during the hot summer months, it was initially the result of a failed attempt at making soda. In 1905, an 11-year-old boy called Frank Epperson had been trying to make himself a sugary beverage, but left his concoction outside overnight with the stirrer still in the cup. Being the middle of winter, the liquid froze, and in the morning Frank enjoyed a frozen treat on a stick. Eighteen years later, he realised the commercial possibilities his accidental invention could have, and he began selling them on California beaches.

So whether it's the result of a clumsy spill or a contaminated laboratory, accidental inventions are just a slapdash scientist away, as long as they are able to realise the potential. Naked celebrations are, of course, optional.

DID YOU KNOW? *Polymers are substances made up of long chains of very similar molecules, making them strong but flexible*

Penicillin

1

A contaminated experiment is any scientist's worst nightmare, but in the case of biologist Alexander Fleming, it would be his making. While studying the influenza virus, he accidentally left a petri dish out of the incubator while he was away on holiday. Upon returning, he discovered that the petri dish, in which he had been growing staphylococcus bacteria, had also begun to grow mould. When Fleming examined the dishes more closely he noticed that there was a ring around the mould where the bacteria had not grown. The 'mould juice' was actually penicillin, produced by the Penicillium mould that had contaminated the dish. Fleming later found that it was able to kill many different types of bacteria. It was two other scientists, Howard Florey and Ernst Chain, who turned penicillin into a drug, but without Fleming, antibiotics may never have been invented.

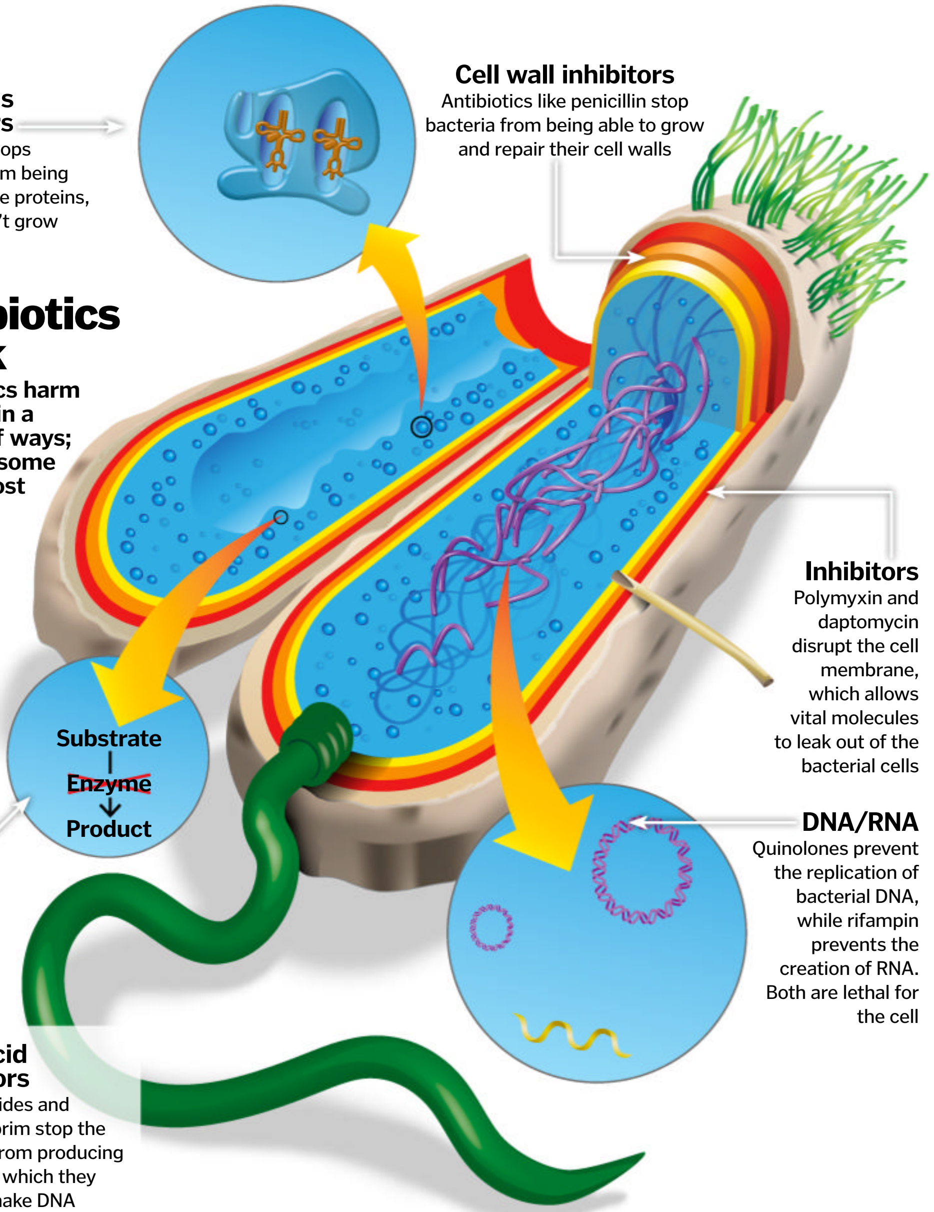
DISCOVERER CASE FILE

Sir Alexander Fleming

Born in Scotland in 1881, Fleming went on to study at St Mary's Hospital, London, where he completed a bachelor's degree in medicine. His accidental discovery of penicillin earned him a Nobel Prize, which he shared with Florey and Chain.

How antibiotics work

Antibiotics harm bacteria in a variety of ways; here are some of the most common



Protein synthesis inhibitors
This type stops bacteria from being able to make proteins, so they can't grow

Cell wall inhibitors
Antibiotics like penicillin stop bacteria from being able to grow and repair their cell walls

Inhibitors
Polymyxin and daptomycin disrupt the cell membrane, which allows vital molecules to leak out of the bacterial cells

DNA/RNA
Quinolones prevent the replication of bacterial DNA, while rifampin prevents the creation of RNA. Both are lethal for the cell

Folic acid inhibitors
Sulfonamides and trimethoprim stop the bacteria from producing folic acid, which they need to make DNA

Plastics (Bakelite)

2

Throughout the 19th century, scientists tried desperately to solve the mystery of polymers – very large molecules that can be expanded and moulded. In 1870 an American inventor modified a naturally occurring polymer called cellulose to create an incredible new material called celluloid, which could be moulded or rolled when heated. But it would be another 40 years before the first wholly synthetic plastic was made. The discoverer, Leo Baekeland, had been experimenting with synthetic resins. After heating the liquid, he found that it produced a solidified matter, which was insoluble in solvents and did not soften when heated. He called it 'Bakelite', and it was soon used in the production of everything from electricals to jewellery.

Bakelite was used to make telephone casings because it was electrically nonconductive and heat-resistant

© Alamy; Thinkstock; WIKI

DISCOVERER CASE FILE

Leo Baekeland

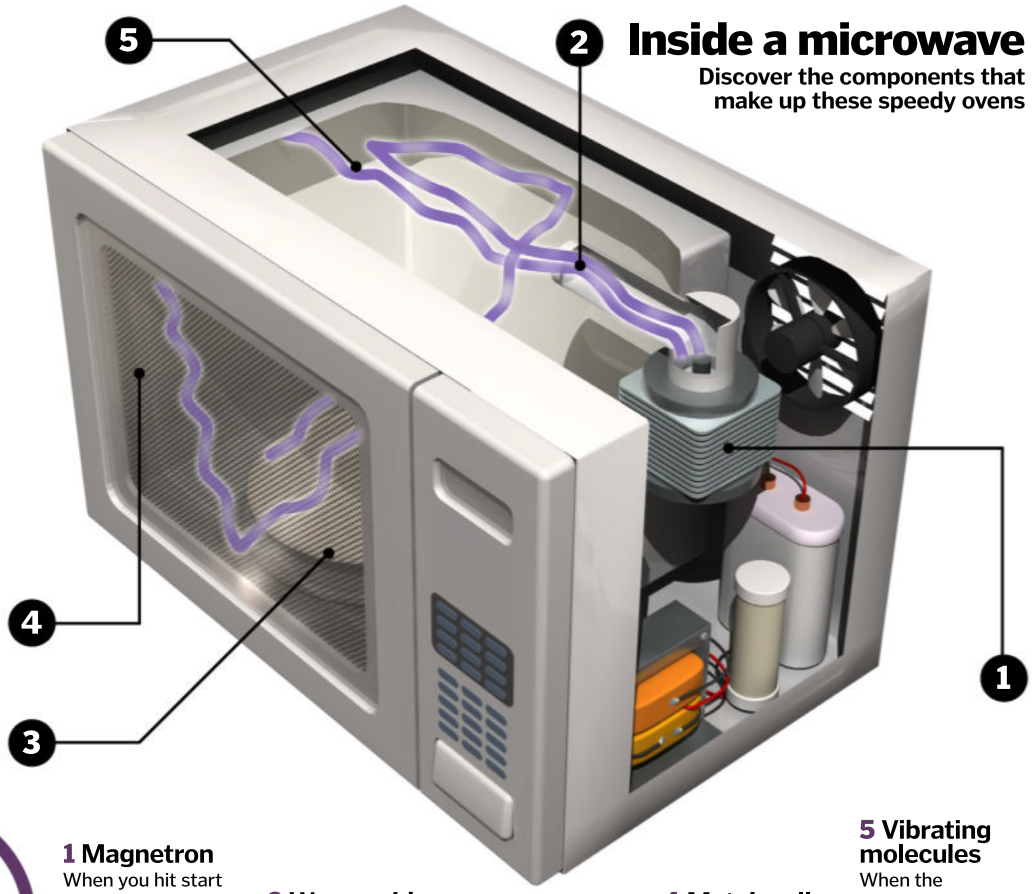
A Belgian chemist born in 1863, Baekeland left his homeland for New York aged 23. Here he invented Velox photographic paper, which allowed developments under artificial light, before turning to plastics.

Microwave

3 Not only was the microwave discovered by accident, it was also discovered by a man who had not even completed high school. At the age of 12, Percy Spencer left education to work in a spool mill and was later hired to install electricity in a nearby paper mill. In the 1920s, Spencer began working as an engineer for Raytheon, a company that went on to improve radar technology for Allied forces in World War II. One day, he was stood in front of an active radar magnetron when he noticed the chocolate bar in his pocket had melted. He began testing the effects of magnetrons on other foods, and invented the first true microwave oven by attaching a high-density electromagnetic field generator to an enclosed metal box. The oven was a success, and in 1945 the company filed a patent for the first commercial microwave.

Inside a microwave

Discover the components that make up these speedy ovens



1 Magnetron
When you hit start on a microwave, the magnetron takes electricity from the power outlet and converts it into high energy microwaves

2 Wave guide
These waves are blasted into the food compartment through a channel called a wave guide

3 Turntable
The food spins around on a turntable, allowing it to be cooked evenly

4 Metal walls
The microwaves bounce off the reflective metal walls to hit the food from different angles

5 Vibrating molecules
When the microwaves penetrate the food, they cause the molecules inside it to vibrate faster. This quickly heats the food up

DISCOVERER CASE FILE

Percy Spencer

Born in 1893, at eighteen months old Spencer's father died and his mother left him in the care of his aunt and uncle. Despite his difficult start, he would become one of the world's most famed physicists.

Artificial sweetener

4 The first artificial sweetener, saccharin, was discovered by a Russian chemist called Constantin Fahlberg. He had been experimenting with preservatives in his work, and while eating a bread roll, he noticed that it had been sweetened by the substance left on his hands. He went back to the lab and retraced his steps, until he was able to synthesise the sweetener in bulk.

DISCOVERER CASE FILE

Constantin Fahlberg

Fahlberg was initially hired to analyse the purity of sugar.

Süßstoff Saccharin
100 Schachteln zu 100 Tabletten
Deutsche Süßstoff-Ges. m. b. H. Berlin W 35

Saccharin rose to popularity during World War II, when sugar became scarce

DURO
SUPER GLUE

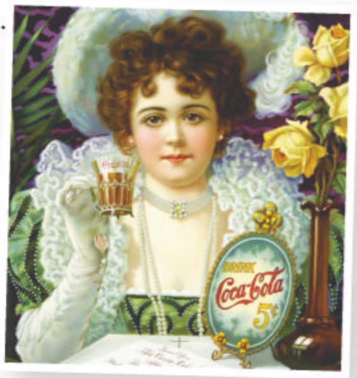
Superglue

5 This super-sticky substance was discovered by accident – twice! Chemist Harry Coover had been attempting to make clear plastic gun sights for the Second World War, and one formulation he tested produced an extremely quick bonding adhesive. It was useless for his gun sights, though, and he forgot about it until almost ten years later, when he stumbled across it again while developing heat-resistant canopies for jet airplanes. This time he realised its potential, and the product was put on the market.

DISCOVERER CASE FILE

Harry Coover

Coover worked as a chemist for Eastman Kodak.



Coca-Cola

6 After being wounded in the American Civil War, pharmacist John Pemberton became addicted to morphine. Seeking an alternative, in 1886 he began experimenting with coca – the plant from which cocaine is derived. He eventually stirred up a fragrant, caramel-coloured liquid that he combined with carbonated water and put on sale for five cents a glass. The soda, named Coca-Cola, would become the world's fourth most valuable brand.

DISCOVERER CASE FILE

John Pemberton

Pemberton established a wholesale drug business.

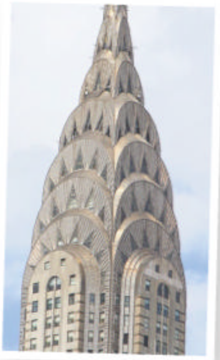
Stainless steel

7 Steel has been forged for millennia, but it wasn't until 1913 that a metallurgist called Harry Brearley discovered a way to stop it rusting. He had been tasked with finding an erosion-resistant metal to prolong the life of gun barrels. Legend has it that as attempt after attempt failed, his pile of scrap metal grew bigger, and he later noticed that one of the scraps hadn't rusted like the others. He had invented stainless steel, and quickly saw its potential in the cutlery industry.

DISCOVERER CASE FILE

Harry Brearley

Brearley was lead researcher at Brown Firth in 1908.



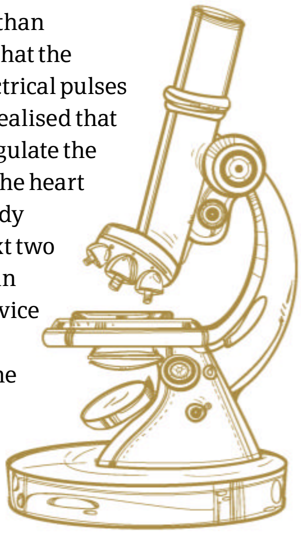
The pinnacle of New York's Chrysler Building is clad with non-rusting stainless steel

DID YOU KNOW? *It wasn't until Thomas Edison's assistant died of skin cancer in 1904 that concerns were raised about X-rays*

Pacemaker

8

Pacemakers have existed in a very rudimentary form since the 19th century, when it was discovered that electrical impulses could be used to provoke a heartbeat. However, the devices that followed were large and bulky and had to be plugged into a mains current, putting the patient at risk of electrocution. It wasn't until 1960 that battery-powered implantable pacemakers came into use, having been invented four years previously. Electrical engineer Wilson Greatbatch was working on a heart-rhythm recorder when he added the wrong size of resistor to the circuitry. Rather than recording, he found that the device produced electrical pulses instead. He quickly realised that it could be used to regulate the electrical activity of the heart and guarantee a steady rhythm. Over the next two years, he succeeded in miniaturising the device and making it safe from bodily fluids. The first patient, a 77-year-old man, went on to live for a further 18 months.



DISCOVERER CASE FILE

Wilson Greatbatch

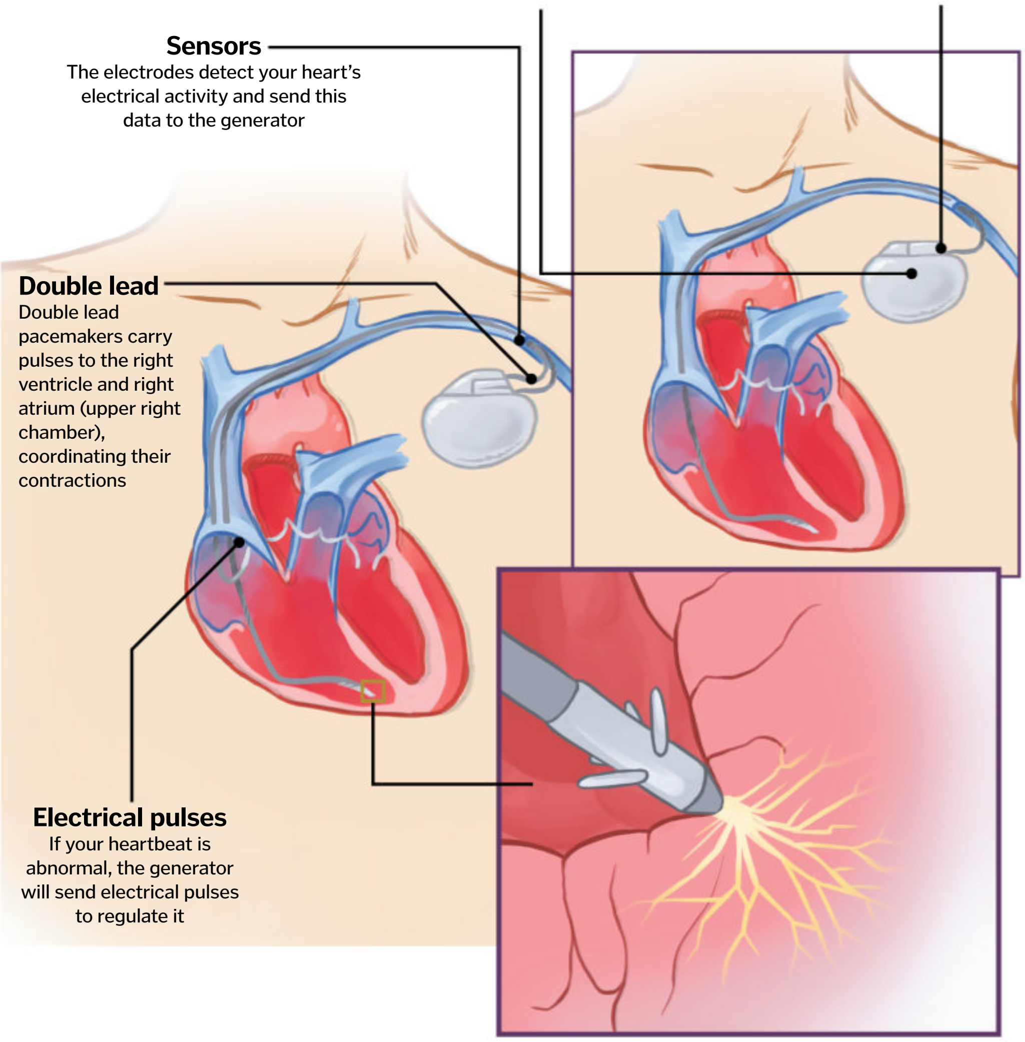
The American engineer and inventor was born in New York in 1919, and served in World War II before completing a degree in electrical engineering. By the time of his death in 2011, he held over 325 patents.

How a pacemaker works

Discover how these amazing pieces of tech can keep our hearts beating

Composition
A pacemaker consists of a battery, a generator and a series of wires with sensors (electrodes) at their tips

Single lead
Single lead pacemakers usually carry pulses from the generator to the right ventricle (the lower right chamber of the heart)



Sensors
The electrodes detect your heart's electrical activity and send this data to the generator

Double lead
Double lead pacemakers carry pulses to the right ventricle and right atrium (upper right chamber), coordinating their contractions

Electrical pulses
If your heartbeat is abnormal, the generator will send electrical pulses to regulate it

Teflon

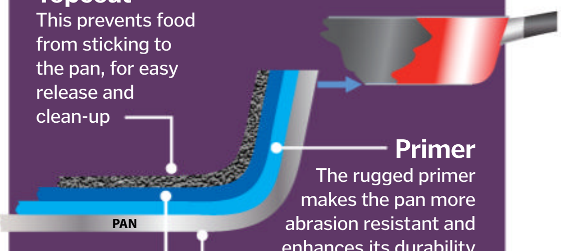
9

The non-stick substance found on frying pans was inadvertently invented by a man called Dr Roy Plunkett. He had been trying to synthesise a non-toxic alternative to refrigerants like sulphur dioxide and ammonia, and was experimenting with tetrafluoroethylene (TFE). After storing the gas in cylinders, he opened one to discover that it had polymerised into a waxy white powder that was extremely sticky and had a very high melting point. Three years later, the substance, which was named Teflon, was patented.

DISCOVERER CASE FILE
Roy Plunkett
Plunkett received the John Scott Medal for the "comfort of humankind".

Protecting a pan

Peel back the layers to find out what makes modern frying pans so practical



Topcoat
This prevents food from sticking to the pan, for easy release and clean-up

Primer
The rugged primer makes the pan more abrasion resistant and enhances its durability

Midcoat
A tough midcoat provides resistance to scratches and abrasions

Base
The hard base is usually made from aluminium or stainless steel

X-Rays

10

It was while German physicist Wilhelm Röntgen was investigating the effects of cathode ray tubes that he made a curious discovery. During an 1895 experiment, he evacuated the tube of all air and filled it with gas before passing an electric current through it. Despite it being covered with black paper, he noticed that a screen several feet away was illuminated by the invisible rays, which he named 'X' to indicate the unknown. They were later found to pass through human tissue, allowing for the imaging of bones.

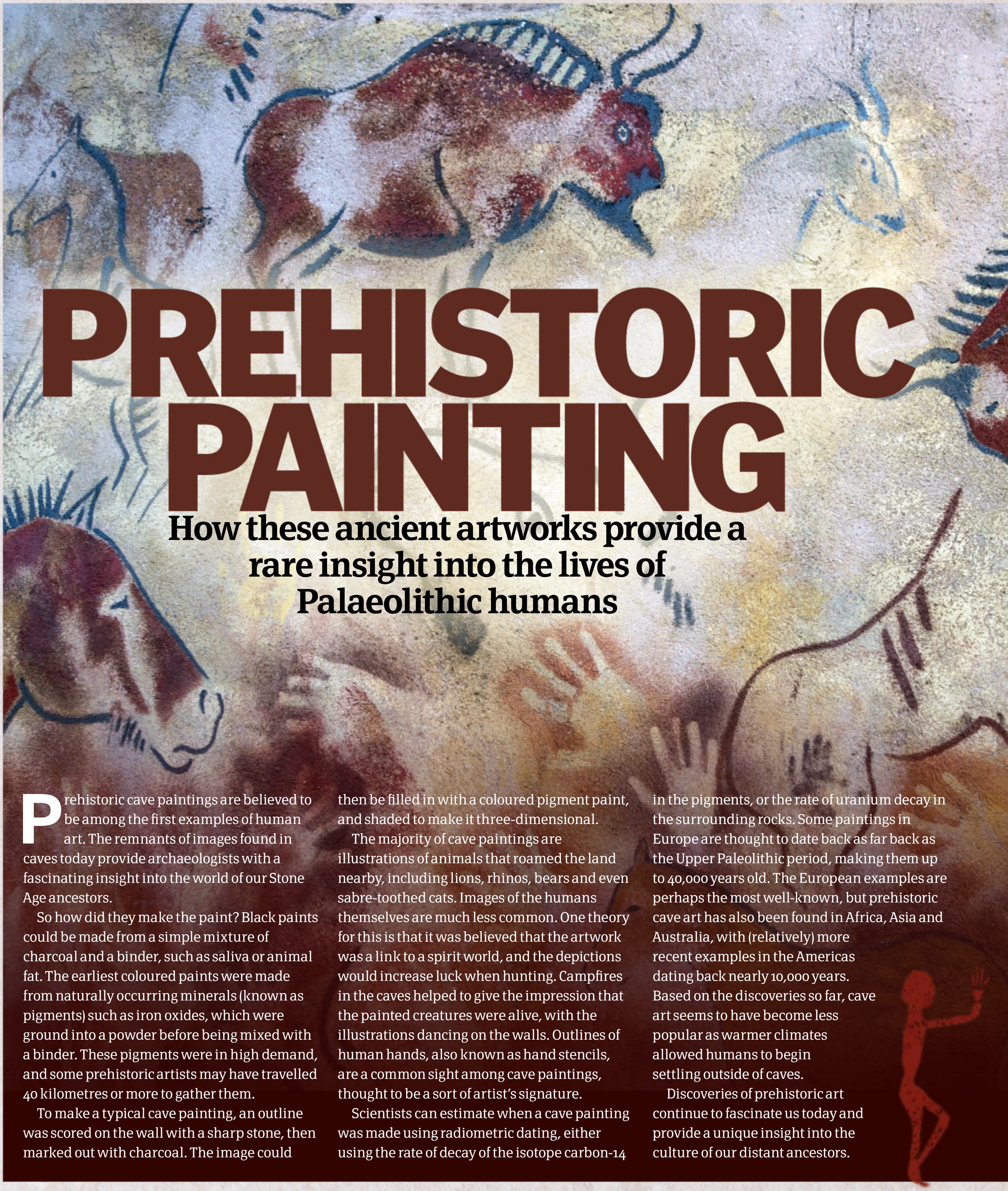
DISCOVERER CASE FILE

Wilhelm Röntgen

Born the only child of a cloth merchant in 1845, Röntgen studied mechanical engineering.

Röntgen took this radiograph of his wife's left hand

© Alamy; Thinkstock; WIKI



PREHISTORIC PAINTING

How these ancient artworks provide a rare insight into the lives of Palaeolithic humans

Prehistoric cave paintings are believed to be among the first examples of human art. The remnants of images found in caves today provide archaeologists with a fascinating insight into the world of our Stone Age ancestors.

So how did they make the paint? Black paints could be made from a simple mixture of charcoal and a binder, such as saliva or animal fat. The earliest coloured paints were made from naturally occurring minerals (known as pigments) such as iron oxides, which were ground into a powder before being mixed with a binder. These pigments were in high demand, and some prehistoric artists may have travelled 40 kilometres or more to gather them.

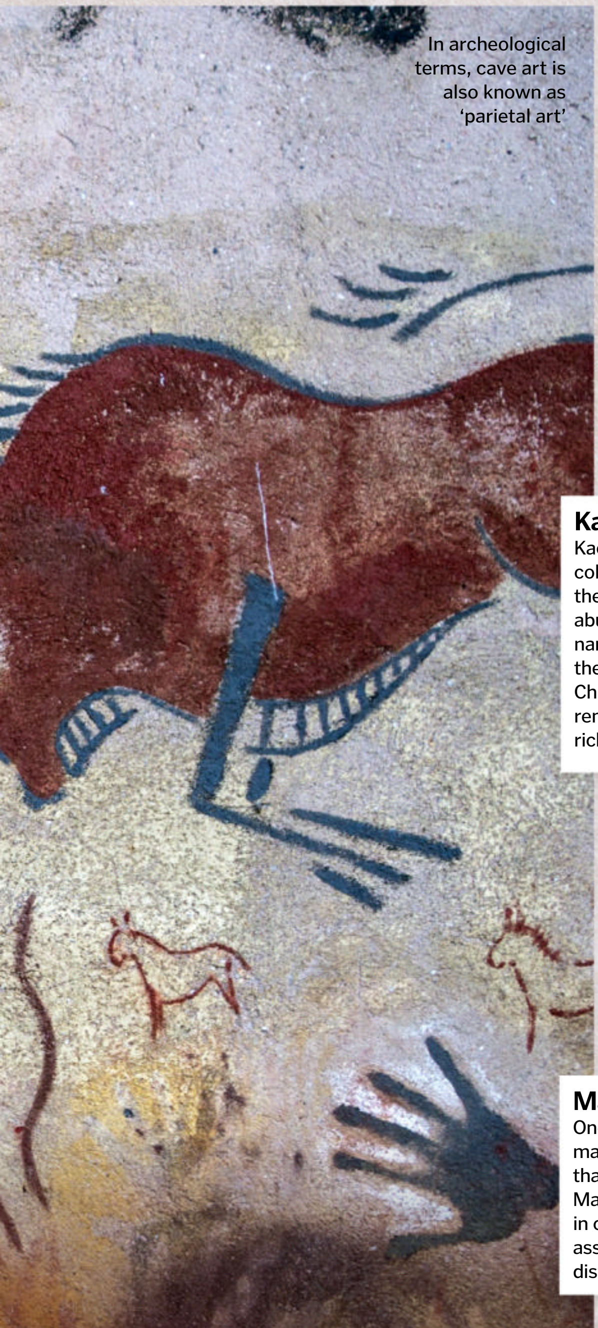
To make a typical cave painting, an outline was scored on the wall with a sharp stone, then marked out with charcoal. The image could then be filled in with a coloured pigment paint, and shaded to make it three-dimensional.

The majority of cave paintings are illustrations of animals that roamed the land nearby, including lions, rhinos, bears and even sabre-toothed cats. Images of the humans themselves are much less common. One theory for this is that it was believed that the artwork was a link to a spirit world, and the depictions would increase luck when hunting. Campfires in the caves helped to give the impression that the painted creatures were alive, with the illustrations dancing on the walls. Outlines of human hands, also known as hand stencils, are a common sight among cave paintings, thought to be a sort of artist's signature.

Scientists can estimate when a cave painting was made using radiometric dating, either using the rate of decay of the isotope carbon-14 in the pigments, or the rate of uranium decay in the surrounding rocks. Some paintings in Europe are thought to date back as far back as the Upper Paleolithic period, making them up to 40,000 years old. The European examples are perhaps the most well-known, but prehistoric cave art has also been found in Africa, Asia and Australia, with (relatively) more recent examples in the Americas dating back nearly 10,000 years. Based on the discoveries so far, cave art seems to have become less popular as warmer climates allowed humans to begin settling outside of caves.

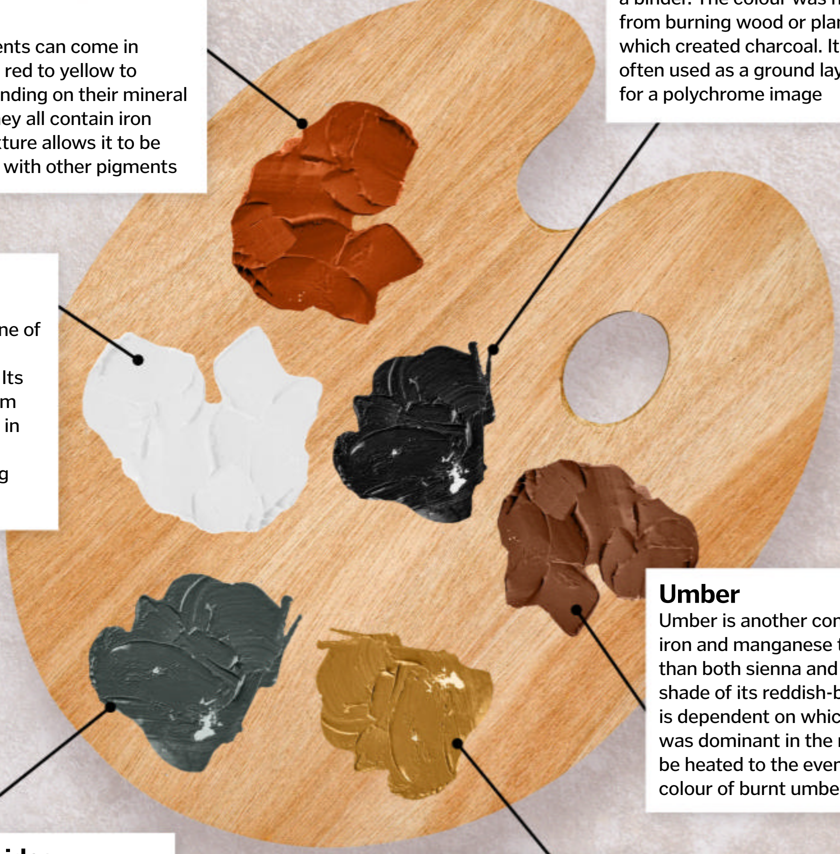
Discoveries of prehistoric art continue to fascinate us today and provide a unique insight into the culture of our distant ancestors.

DID YOU KNOW? *Binders used to create paints could be pretty gruesome, ranging from urine to bone marrow and even blood*


In archeological terms, cave art is also known as 'parietal art'

The prehistoric palette

The colours and shades used to illustrate the Stone Age world



Ochre
Ochre pigments can come in shades from red to yellow to brown, depending on their mineral blend, but they all contain iron oxide. Its texture allows it to be easily mixed with other pigments

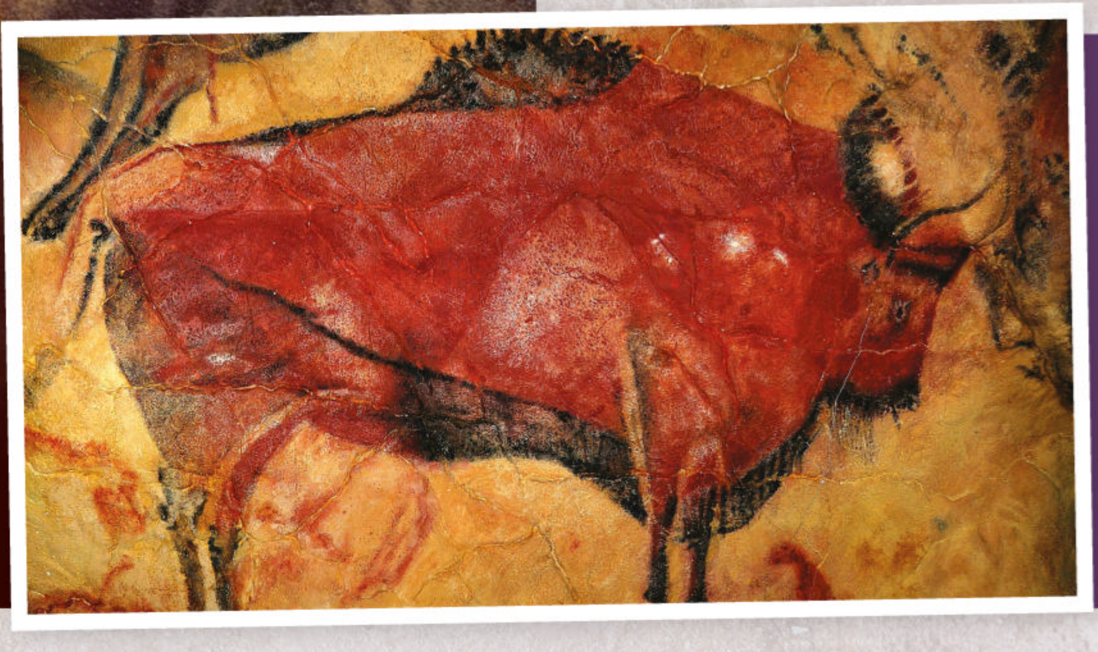
Carbon black
Monochrome paintings were a simple mix of carbon black and a binder. The colour was made from burning wood or plants, which created charcoal. It was often used as a ground layer for a polychrome image

Kaolin
Kaolin is a white-coloured clay and one of the Earth's most abundant minerals. Its name originates from the town of Gaoling in China, which is renowned for having rich kaolin deposits

Umber
Umber is another combination of iron and manganese that is darker than both sienna and ochre. The shade of its reddish-brown colour is dependent on which mineral was dominant in the mix. It could be heated to the even darker colour of burnt umber

Manganese oxides
One of the darkest colours used, manganese oxide could create shades that were brown, grey or black. Manganese deposits weren't common in caves adorned with artwork, so it's assumed painters would trek long distances to find a source

Sienna
A mixture of iron oxide and manganese oxide, raw sienna is a pigment with a yellow-brown colour. When heated, it turned into burnt sienna, which is darker in tone and redder in colour



Green and blue

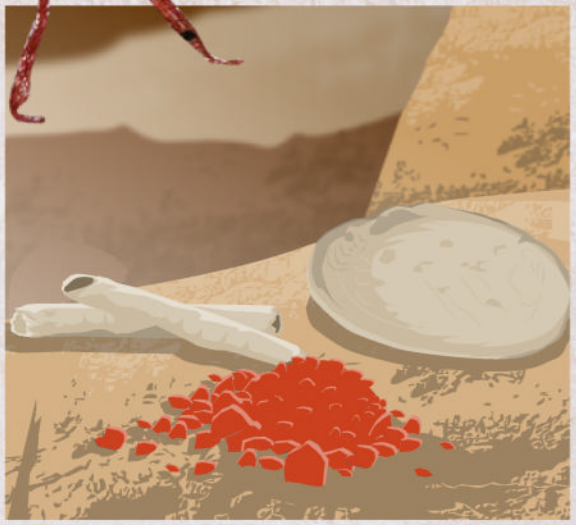
Cave art typically features red, brown, yellow and black, but none of the paintings, it seems, included blue or green. This can be explained in part by the lack of natural pigment sources for these shades. In the Palaeolithic period, obtainable blue-coloured minerals were rare, especially in Europe. Blue was used in later eras by the ancient Egyptians, who used powdered azurite to make blue-coloured jewellery. The omission of green shades is more difficult to comprehend, as green coloured minerals like malachite and terre-verte were abundant. One of the reasons given for the lack of green colour is that it may have simply not shown up as well as red or brown does under fire or torchlight.

Clay ochre could be red, yellow or brown, but not blue or green

© Shutterstock; Thinkstock; WIKI

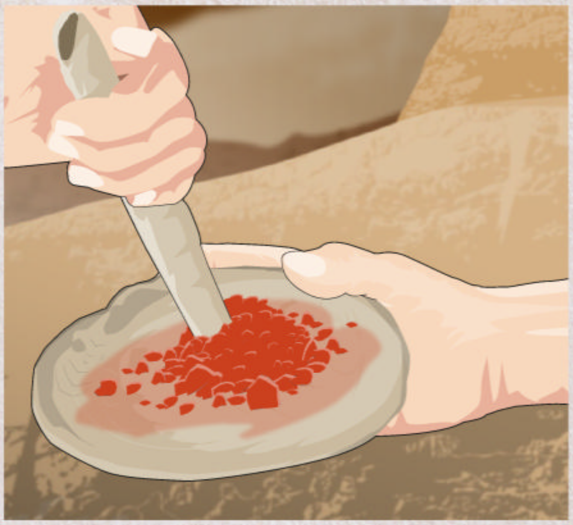
Hand stencils

The techniques used to create the perfect prehistoric hand silhouette



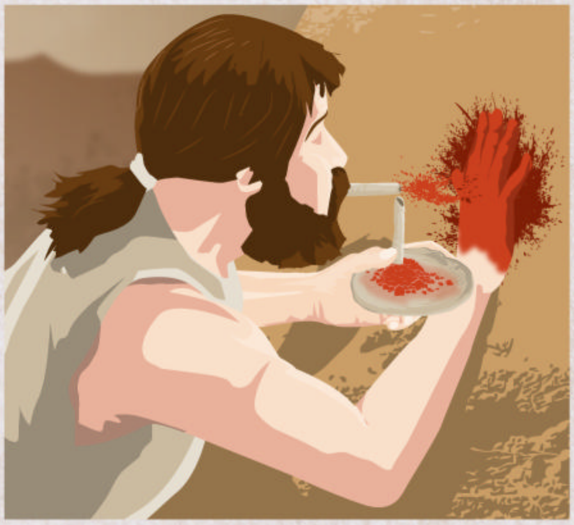
1 Tools for the job

To create a hand stencil, researchers think that prehistoric humans used hollow bones or reeds to blow paint through, and a shell to hold the paint in. The pigment used to make the paint was ground into powder and could be sourced from various minerals.



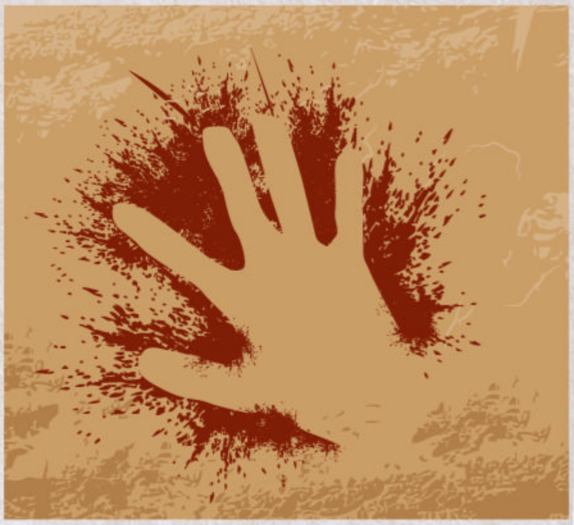
2 Making the paint

The powdered pigment was mixed with a binder in the shell using the reed or bone. Researchers trying to recreate prehistoric hand prints found that to make a paint thin enough to spray, the Palaeolithic painters likely used water as a binder.



3 Creating the stencil

The artist placed one hand on the wall, held one of the reeds/bones in their mouth, and held the shell and second tube (dipped in the paint) in their other hand. Blowing through one tube across the top of the other created a cloud of colour spray on the wall.

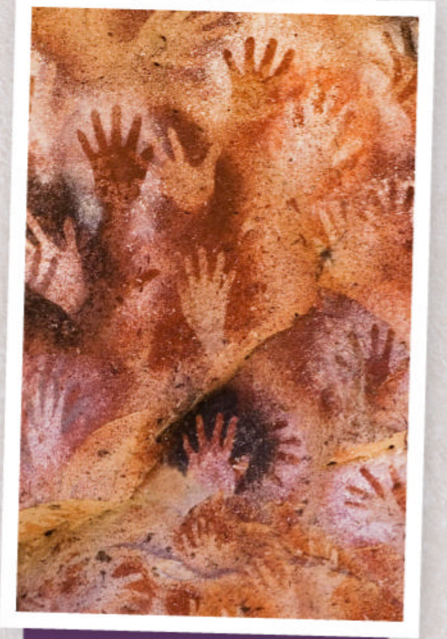


4 Finishing touches

When the artist removed their hand from the wall, they left a silhouette with colour all around it. More colours could be added with brushes, or a charcoal outline could be drawn around the hand. Bumpy walls could also help create a 3D effect.

Whose hands were they?

Experts can determine the gender of the person who made a stencil with over 90 per cent accuracy. The technique that is used is part of a study called geometric morphometrics. Digital versions of modern male and female hand stencils were made and used as a template when measuring those of prehistoric hands. The hands were then compared based on palm shape, which has been found to be a more useful indicator of gender than just measuring finger length and hand size. The study reinforced that both genders would often produce stencils. Researchers can also make an educated guess regarding the handedness of the artists, as the hand that is on the wall would most likely be their weaker side, and the dominant hand would be the one used to hold the pigment.



Hand stencils in Cueva de las Manos (Cave of Hands) in Argentina, created between 13,000 and 9,000 years ago

The world's weirdest pigments

Our artistic ancestors were quite resourceful

Mummy brown

A hugely popular pigment during the 16th century, this was made from the remains of ancient Egyptian mummies. Mixed with myrrh and white pitch, it made a reddish-brown colour.

Tyrian purple

This pigment was made from a dye extracted from murex shellfish. A symbol of imperial authority in the Roman Empire, it was used to colour the emperor's toga.

Lead white

Long before it was known to be poisonous, lead white was used as a paint pigment and also in makeup. One theory is that it contributed to Van Gogh's deteriorating mental health.

Uranium yellow

This yellow-orange pigment was used to create coloured glass and glazes for ceramics. However, this stopped when it was found to be a radioactive and highly toxic substance.

Carmine

Carmine is a deep red colour that has long been associated with royalty and nobility. It is made from the carminic acid that oozes out of some species of crushed beetles.

DID YOU KNOW? *10,000 shellfish were needed to make just one gram of Tyrian purple dye, making it a valuable commodity*

Cave art across the world

The best examples of parietal paintings across the globe, from France to Australia

LASCAUX

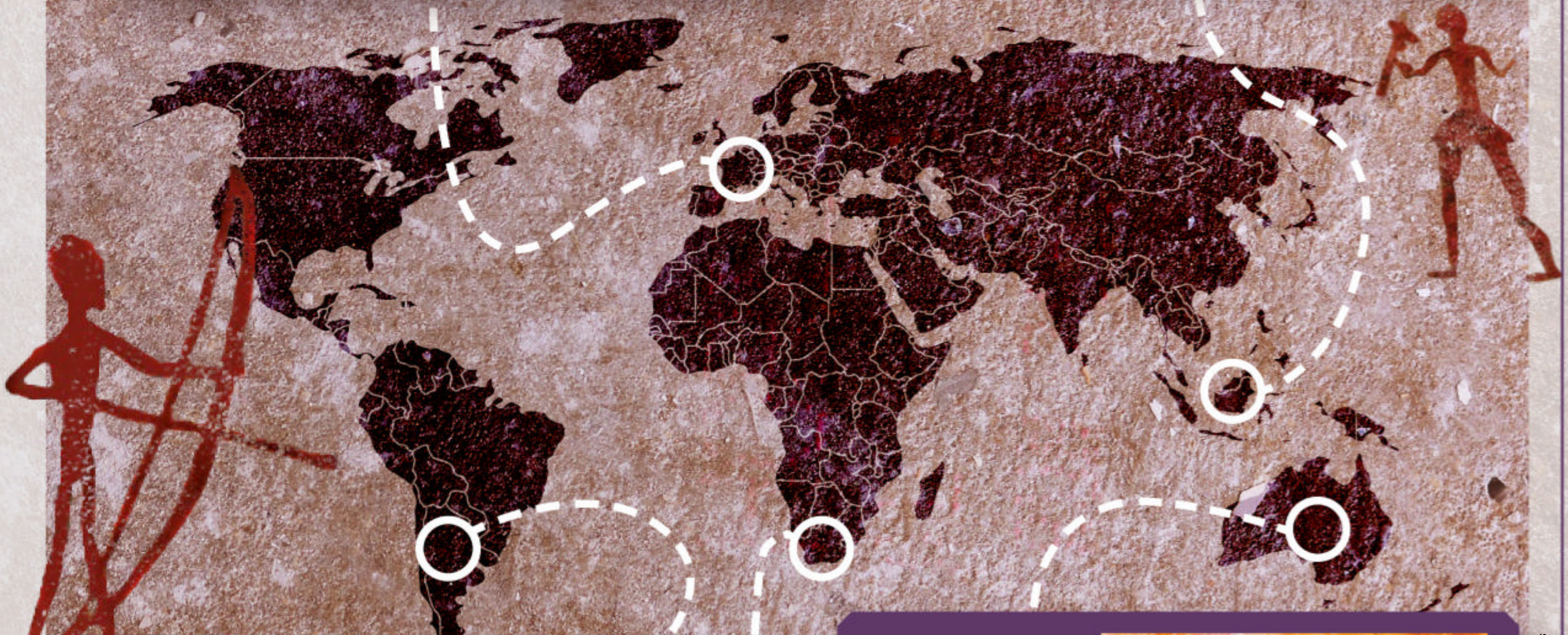
France / 18,000 - 13,000 BCE

With hundreds of paintings and drawings and over 1,500 engravings, Lascaux is one of the best sites for prehistoric art on Earth. The caves include depictions of bison, mammoths, aurochs, lions and wolves among others.

PETTAKERE CAVE

Indonesia / 38,000 BCE

These Indonesian paintings are believed to be proof of prehistoric island-hopping in southeast Asia. The cave includes what are believed to be the oldest hand stencils on Earth.



CUEVA DE LAS MANOS

Argentina / 13,000 - 9000 BCE

The Cave of Hands plays host to some of the oldest known cave paintings in the Americas. The artwork varies from hunting scenes to hand stencils and is red or black in colour.

KIMBERLEY

Australia / 50,000 - 5000 BCE

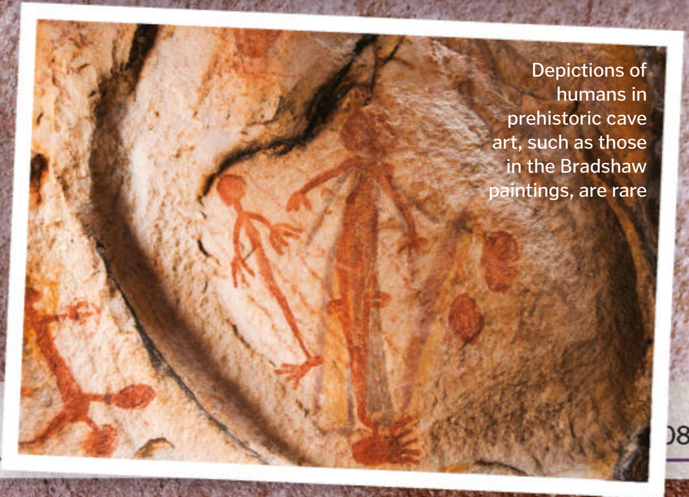
Known as the Bradshaw or Gwion Gwion paintings, the age of the art itself is difficult to determine, but it's possible that this cave is home to some of the oldest artwork of human figures in the world.

> "Some paintings in Europe are thought to be up to 40,000 years old"

BLOMBOS CAVES

South Africa / 100,000 - 70,000 BCE

Archaeologists have unearthed the remains of what appears to be a rudimentary paint workshop in these caves. They found engraved blocks of ochre (shown on the right), shell 'palettes', bone 'spatulas' and grinding equipment.



Depictions of humans in prehistoric cave art, such as those in the Bradshaw paintings, are rare

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INFLUENTIAL FIGURES

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Meet the richest, deadliest and longest-lived monarchs

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How the Renaissance polymath was much more than a painter

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One of the greatest engineers of all time whose designs revolutionised transport

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The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time

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How these siblings played a pivotal role in the evolution of powered flight

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Meet the most influential physicist of all time

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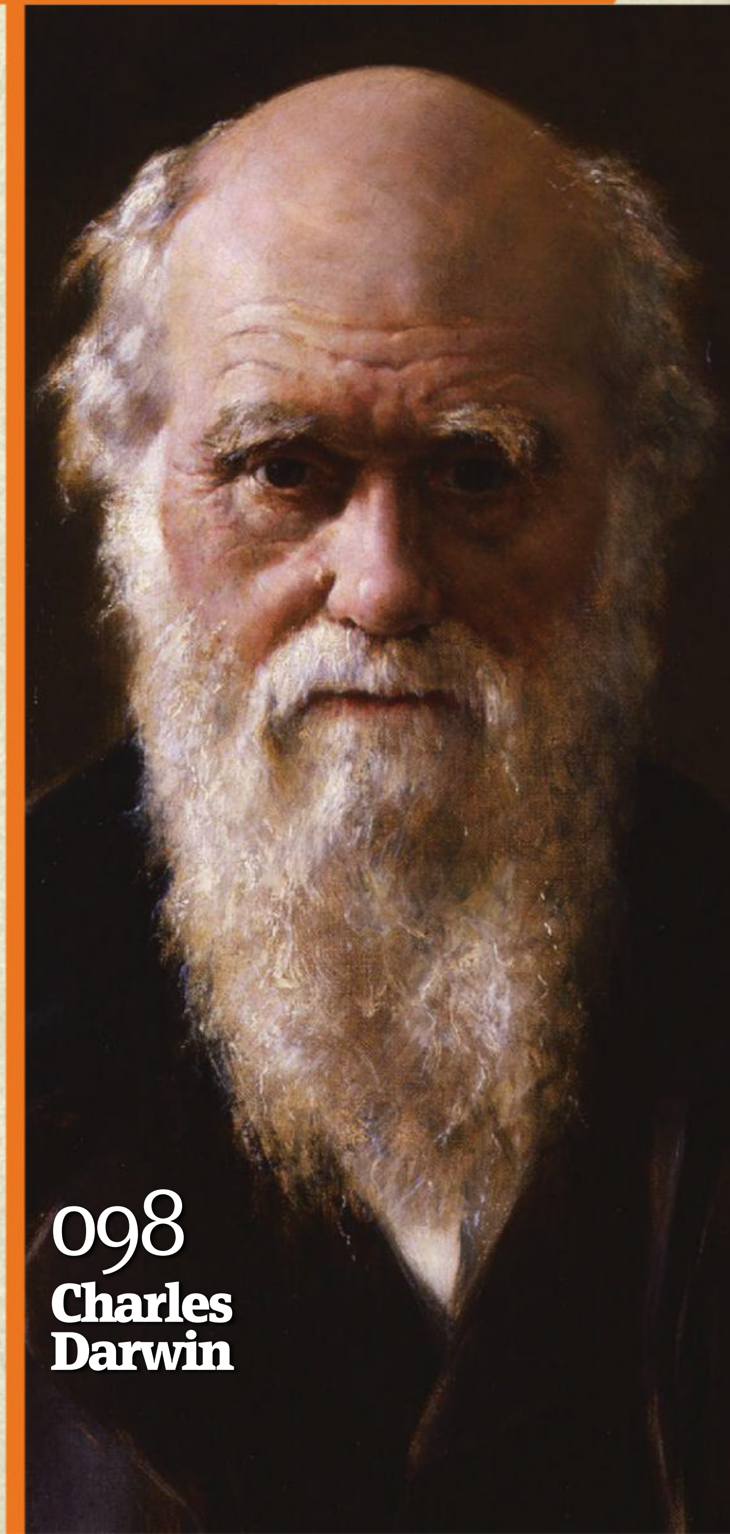
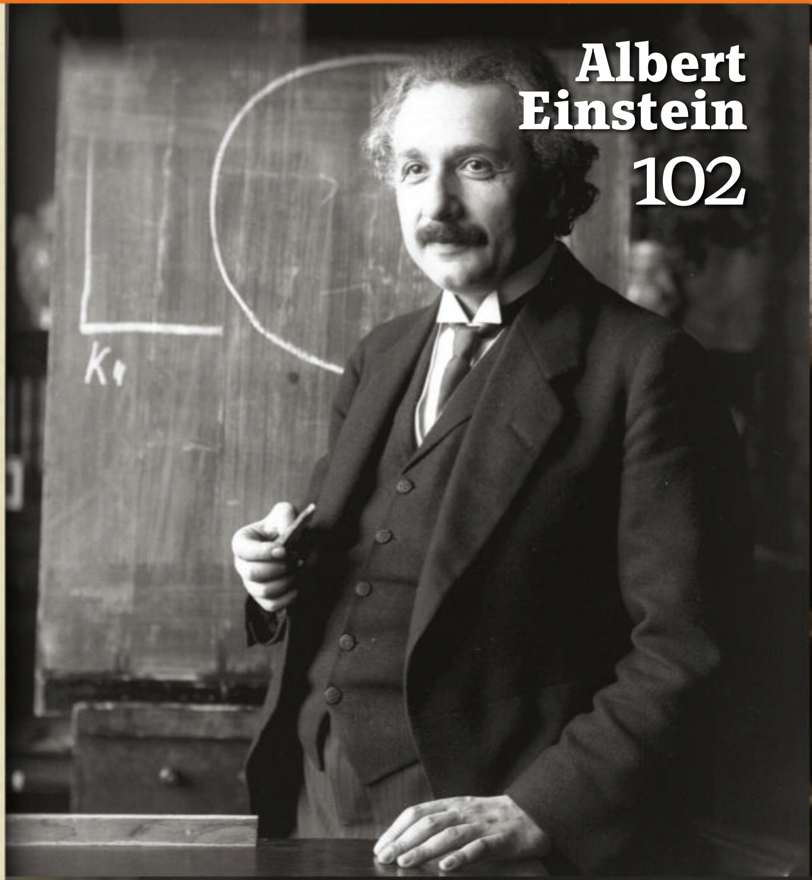
Record-breaking royals



098
Charles Darwin



Albert Einstein
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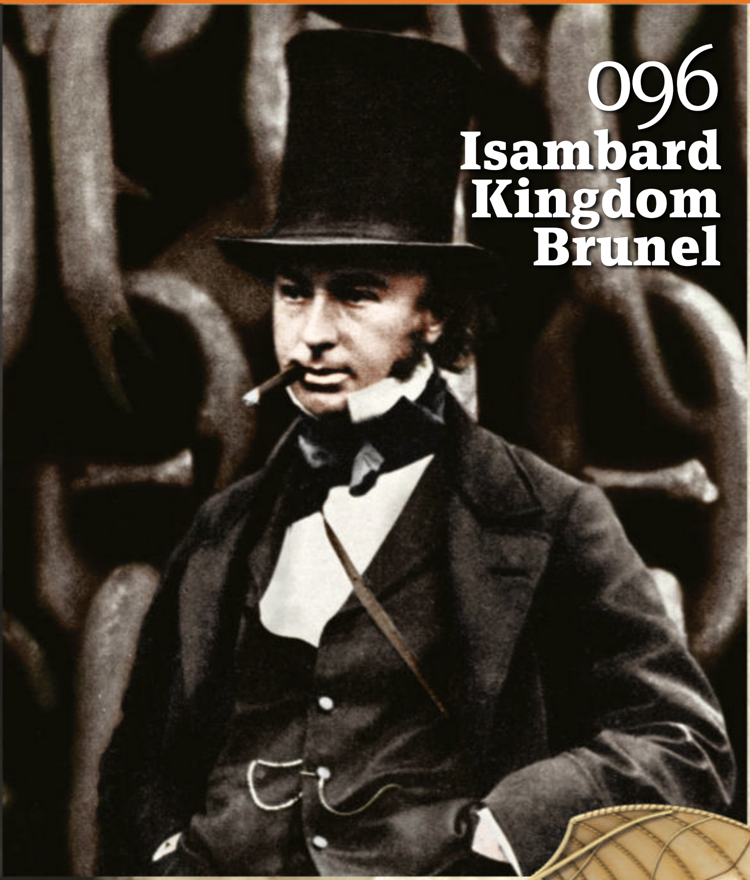


096
Isambard Kingdom Brunel

Leonardo da Vinci
090

Record-breaking ROYALS

Meet the richest, deadliest and longest-lived monarchs and find out who had the most wives, the most money and the most heirs

DID YOU KNOW? *Mary Queen of Scots became the youngest ever British monarch when she ascended the throne at 6 days old*

"According to Forbes, King Bhumibols Adulyadej's wealth amounted to £22 billion"

Richest

King Bhumibol Adulyadej

1946–2016 / Thailand

In 2012, the Guinness World Record holder for the richest royal was King Bhumibol Adulyadej, King Rama IX of the Chakri dynasty of Thailand. According to Forbes, his wealth amounted to £22 billion ($30 billion), and his riches included the largest cut diamond in the world, a 545-carat jewel known as the Golden Jubilee Diamond.

King Bhumibol Adulyadej passed away in 2016, but no royal yet comes close to taking his title. The nearest is Hassanal Bolkiah, the Sultan of Brunei, who was reportedly worth £15 billion ($20 billion) in 2011.

Longest reign

Sobhuza II

1899–1982 / Swaziland

Queen Elizabeth II became the longest-reigning British monarch in 2015, outstripping the record set by her great great grandmother, Queen Victoria. But this doesn't yet match global records.

The longest reigning European monarch was Afonso I of Portugal, who racked up an impressive 73 years and 220 days between 30 April 1112 and 6 December 1185. However, the longest verifiable reign in history belongs to Sobhuza II, Paramount Chief and King of Swaziland, who assumed his position at just four months old and remained on the throne for 82 years.

Even longer reigns are rumoured but challenging to confirm. It's believed that ancient Egyptian pharaoh Phiops II ascended his throne at the age of six in 2281 BCE and remained there for 94 years, and Min Hti, King of Arakan (now part of Myanmar), reigned from 1279 to 1374, a total of 95 years.

Shortest reign

Sultan Khalid bin Barghash

25–27 August 1896 / Zanzibar

There are two Guinness World Record holders for the shortest reign of a monarch, each spending less than half an hour on their thrones.

Louis-Antoine of France was heir apparent when Charles X abdicated after the July Revolution in 1830. He quickly abdicated too, passing the throne to Henry, Duke of Bordeaux, before fleeing to Britain.

Crown Prince Luís Filipe of Portugal also lost his throne to a revolution. His father Dom Carlos I was assassinated in the Lisbon Regicide of 1908, and Luis died 20 minutes later.

Neither of these princes actually had time to rule. The shortest reign of a ruling monarch goes to Sultan Khalid bin Barghash, who lasted just two days after taking the throne in Zanzibar. The British sent warships to siege his wooden palace, defeating him in the shortest war in history, the hour-long Anglo-Zanzibar War.

© Getty

Most travelled

Queen Elizabeth II

1952–2022 / United Kingdom and the Commonwealth

Modern monarchs have the upper hand when it comes to global travel, and Queen Elizabeth II visited more countries than any other royal. In her time on the throne she racked up more than 1.6 million kilometres, despite, amazingly, not having a passport.

As of 2012 the late Queen had made state visits to 116 different countries, including all 53 Commonwealth nations, and by 2016, she'd made 256 official trips in total. But there are some places that remained off-limits. Elizabeth never visited Israel, Egypt, Argentina or Greece, the homeland of Prince Philip.

ABOVE: Queen Elizabeth II during a 1975 visit to Hong Kong
RIGHT: The Queen and Prince Philip in Canada, July 1970

Face on most currencies

Queen Elizabeth II

1952–2022/ United Kingdom and the Commonwealth

Queen Elizabeth II appears on coins in over 35 different countries, including Australia, Bahamas, Belize, Bermuda, Canada, Cayman Islands, Cyprus, Dominica, Falkland Islands, Fiji, Gibraltar, Guernsey, Hong Kong, Jamaica, New Zealand, Mauritius, Papua New Guinea, Seychelles, South Africa, St Helena, and the UK. They are still legal tender after her death.

AUSTRALIA
1
ANH 666853
FIJI
D/10078628
E DOLLAR
$1

Queen Elizabeth II's portrait has appeared on banknotes all over the world

Most heirs

King Abdulaziz Al-Saud

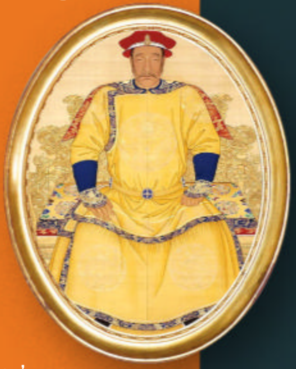
1932–1953 / Saudi Arabia

King Abdulaziz Al-Saud founded Saudi Arabia in 1932 and had 45 sons, from whom every Saudi king is descended. The number of daughters he fathered is not known, but Saudi Arabia's royal family now has over 15,000 members. His eldest son, King Saud, had 52 sons and 54 daughters.

Deadliest

Nurhaci, Tianming Emperor

1616–1626 / Liaoning, China



Nurhaci, the Tianming emperor, spearheaded the overthrow of the Ming dynasty. He was leader of the Manchu people of northern China, who were fed up with the famine, silver shortages and tax rises of the early 1600s. He put together a declaration of war known as the 'seven grievances', and the result was one of the bloodiest conflicts in recorded history. The Ming dynasty was replaced with the Qing dynasty and, in the process, an estimated 25 million people died. In the battle of Yangzhou, lead by Nurachi's son, Prince Dodo, 800,000 died.

Most wives

King Ibrahim Njoya

1886–1933 / Bamum (now western Cameroon)

Henry VIII is renowned for having six wives, but he doesn't come close to the record for royal spouses. King Ibn Saud of Saudi Arabia reportedly had 30; King Sobhuza II of Swaziland is rumoured to have had over 100; and King Ibrahim Njoya of Bamum had over 600.

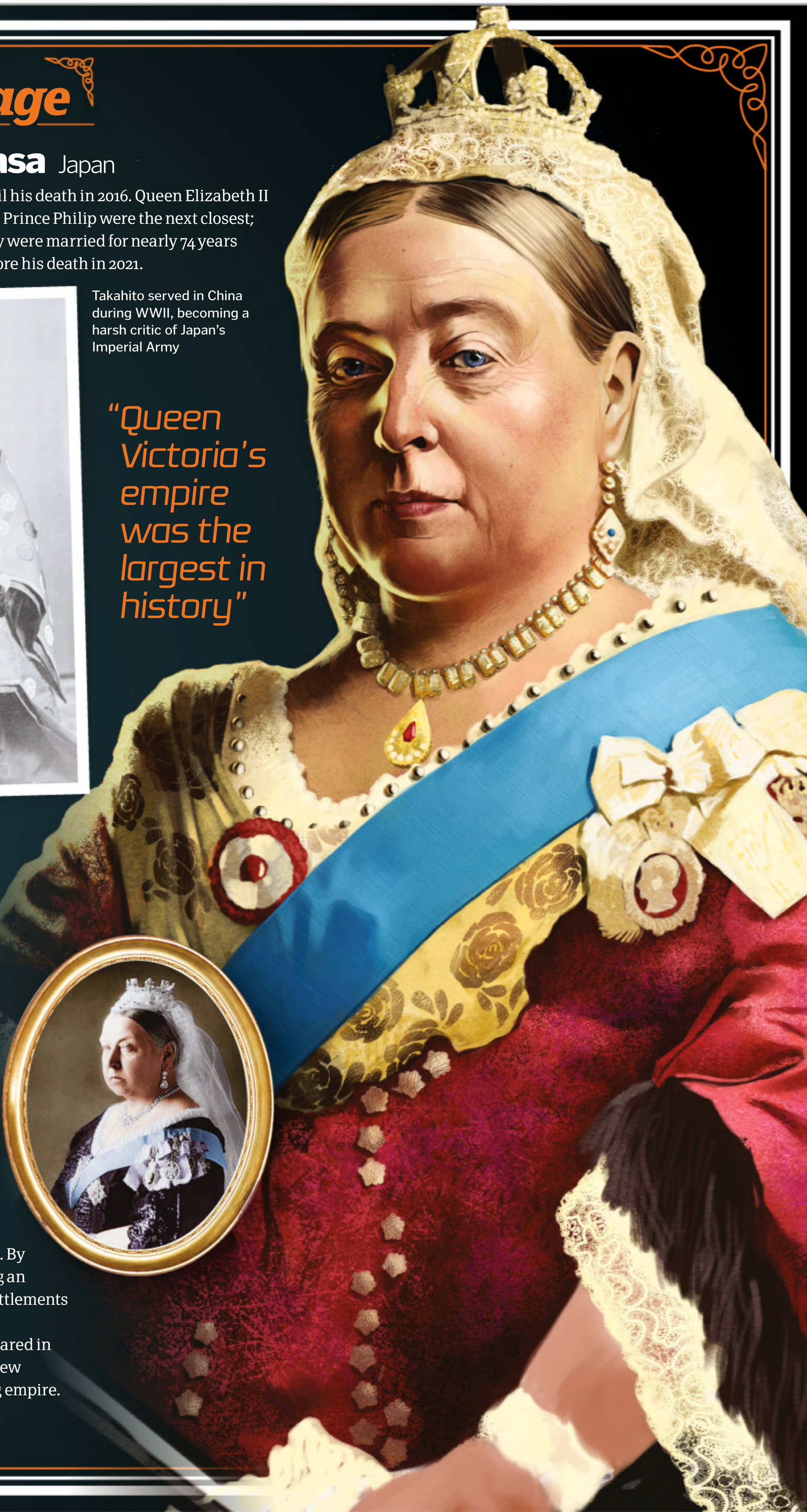
Longest marriage

Takahito, Prince Mikasa Japan

This hotly contested record is currently held by Takahito, Prince Mikasa of Japan. He married Yuriko, Princess Mikasa, in 1941 and they were together for 75 years until his death in 2016. Queen Elizabeth II and Prince Philip were the next closest; they were married for nearly 74 years before his death in 2021.

Takahito served in China during WWII, becoming a harsh critic of Japan's Imperial Army

> *"Queen Victoria's empire was the largest in history"*



Widest rule

Queen Victoria

1837–1901 / United Kingdom of Great Britain and Ireland, India

The British Empire has its roots in the 16th century, but it wasn't until the reign of Queen Victoria that it reached its peak. Her empire was the largest in history, covering more one-fifth of the world.

Competition with other European countries had driven the formation of British colonies, trading across the globe in tobacco, sugar, tea, silk, cotton, indigo dye and slaves. The first were set up in North America in the 1600s, then in Jamaica in 1655, and northwestern Canada in 1670. By 1661, the British began moving into Africa, settling an island in the Gambia River, and in 1788 the first settlements sprang up in Australia.

At the start of Victoria's reign colonies had appeared in South Africa, and during her time on the throne New Zealand and Egypt were added to the vast trading empire. In 1877 Victoria became Empress of India.

THE GENIUS OF DA VINCI

So much more than just a painter, the famous Renaissance polymath invented a plethora of marvellous machines

Leonardo di ser Piero da Vinci was the epitome of a Renaissance man. While renowned as an artist, da Vinci was also a brilliant scientist and engineer. Beyond his famous paintings, such as *The Last Supper* and the *Mona Lisa*, da Vinci's journals reveal a range of studies and observations, from anatomy to astronomy, and palaeontology to philosophy.

The Renaissance ('rebirth') was a period of cultural revival, which began on the Italian Peninsula in the 14th century as the Middle Ages came to an end. Da Vinci was born in 1452 into a world that had become more accommodating to new ideas. A year after his birth, the capital of the Byzantine Empire, Constantinople (now Istanbul), fell to the Ottomans. As talented scientists and artists escaped the war-torn Bosporus to seek safety in Italian city-states, the country became a hub of learning. One city the fleeing scholars settled in was Florence.

Here they were encouraged to study and invent by the ruling Medici family, who happily bankrolled learning centres all over the city. An intellectual and cultural revolution began; new technological and scientific ideas were spread with help from the recent invention of the printing press, as Europe began to catch up with academics from the Islamic world. It is likely that the inventions and creations of other Renaissance men like Mariano di Jacopo (also known as Taccola) and Filippo Brunelleschi influenced da Vinci, who revelled in the idea of Renaissance Humanism, a notion that encouraged learning and built on critical thinking methods that had stagnated in the Medieval period.

Da Vinci's most famous works are his paintings, but he was also a creative and talented engineer and inventor. The rediscovery of his codices in the 19th century revealed plans for an array of contraptions, from battlefield tanks to flying machines. His ideas were influenced by classical antiquity and observations of the natural world. For example, a tortoise shell was the inspiration for his armoured car, while observations of birds, bats, flying fish and even plants contributed to the designs of his various flying machines.

His ideas were ambitious, but they were grounded in logical calculations based on scientific theories and mathematical principles. For the most part, these designs were only held back by the technological restrictions of the time. While many of da Vinci's manuscripts were inadvertently destroyed after his death, over 5,000 pages of his journals still exist today, providing us with a glimpse into the mind of a man ahead of his time. Leonardo da Vinci may have died nearly 500 years ago, but the legacy of his creativity and innovation lives on.

DID YOU KNOW? *Da Vinci wrote about his aerial screw 450 years before the first helicopter, the VS-300, took to the skies*

FLYING MACHINES

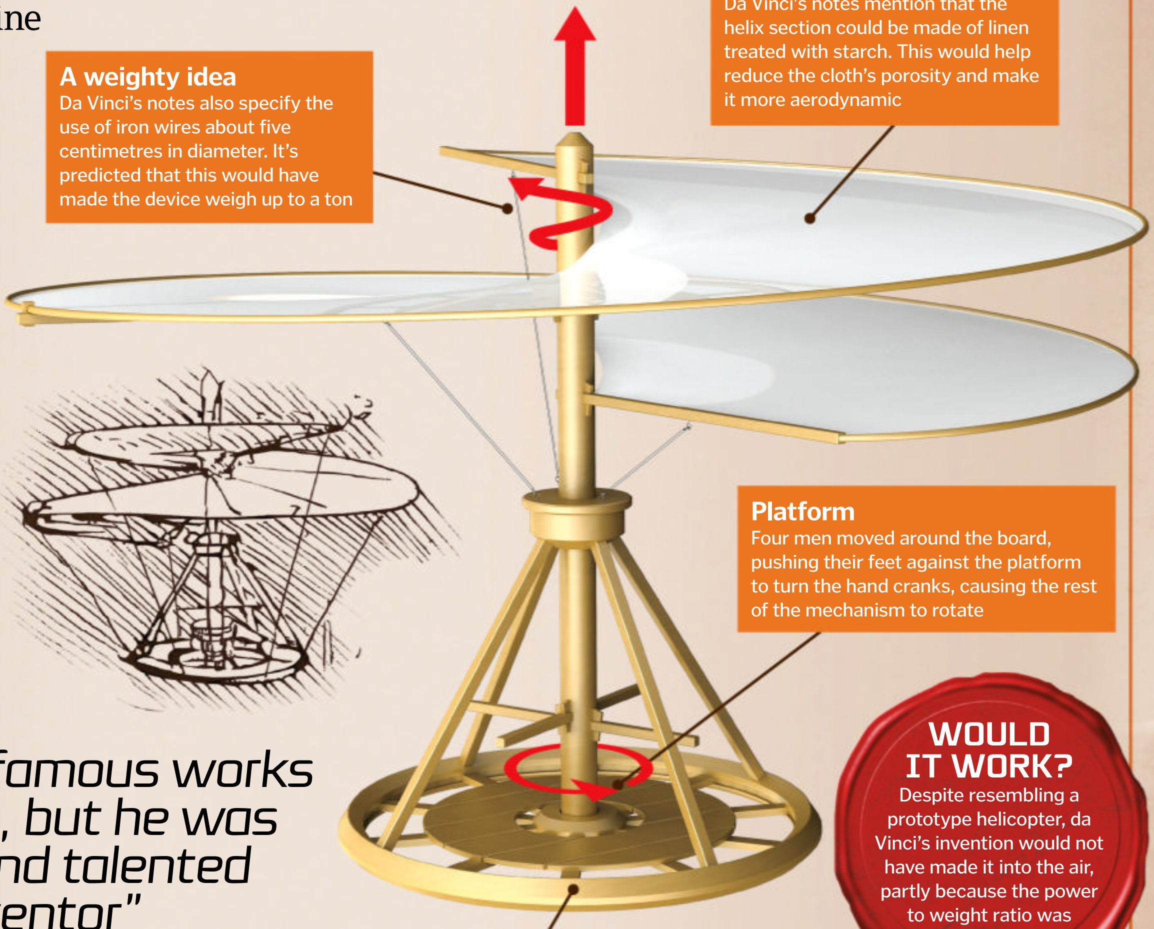
Da Vinci dreamed of mechanisms that would enable humans to soar through the sky

Aerial screw

An ambitious flying machine that helped inspire the modern helicopter

Scribbling in his notebook circa 1489, da Vinci envisioned a spiral-shaped contraption that could take to the skies. Possibly powered by hand cranks turned by four people, his writings suggested that the aerial screw could achieve flight by rotating quickly around a central shaft. Da Vinci believed that air could be compressed, so just as a screw bores into the ground below, his machine could 'bore' into the air above to lift his machine up off the ground.

Unfortunately, materials that were strong and light enough for the device to work were not available at the time. What's more, it would not have been able to fly for long, as once it was off the ground, the screw would no longer have a support structure to press against in order to keep spinning. It may never have made it off the ground, but da Vinci's innovative aerial screw design was the first to study the potential of a rotating spiral for flight.



A weighty idea
Da Vinci's notes also specify the use of iron wires about five centimetres in diameter. It's predicted that this would have made the device weigh up to a ton

Materials
Da Vinci's notes mention that the helix section could be made of linen treated with starch. This would help reduce the cloth's porosity and make it more aerodynamic

Platform
Four men moved around the board, pushing their feet against the platform to turn the hand cranks, causing the rest of the mechanism to rotate

Lift off?
One hurdle encountered in this study was to figure out how to produce high enough speeds to generate the required lift

> *"Da Vinci's most famous works are his paintings, but he was also a creative and talented engineer and inventor"*

WOULD IT WORK?
Despite resembling a prototype helicopter, da Vinci's invention would not have made it into the air, partly because the power to weight ratio was so low.

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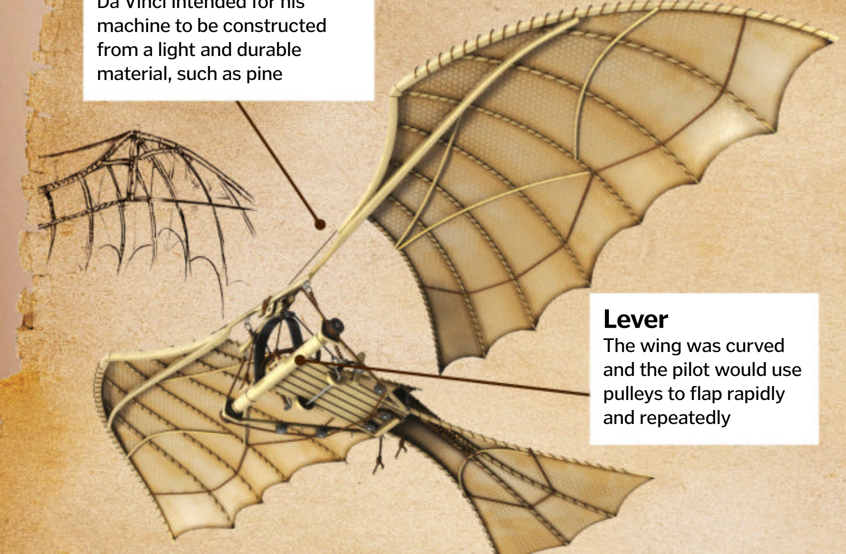


Frame
Da Vinci intended for his machine to be constructed from a light and durable material, such as pine

Lever
The wing was curved and the pilot would use pulleys to flap rapidly and repeatedly

Ornithopter

Enthused by birds soaring in the air, da Vinci drew some inventive designs for mechanical wings

Da Vinci observed birds and other animals in flight, and became obsessed with the idea of a contraption that would allow humans to do the same. One of his ideas was an ornithopter, which was powered by flapping mechanical wings. Da Vinci wrote over 35,000 words and drew 500 sketches on flying machines. He understood that birds relied on both lift and propulsion to maintain flight, and that they balanced themselves with both wings and tail. He hinted at the idea of gravity and understood that flying machines had to be as lightweight as possible. His sketches demonstrate knowledge of aerodynamics, showing how airflow could be streamlined and how aircraft produce drag. The only drawback was the human body, which is simply not built to achieve flight on its own, nor muscular enough to power a mechanical engine for flight.

WOULD IT WORK?
Ornithopters with flapping wings have been built, both manned and unmanned. They can work with the help of an engine.

WAR MACHINES

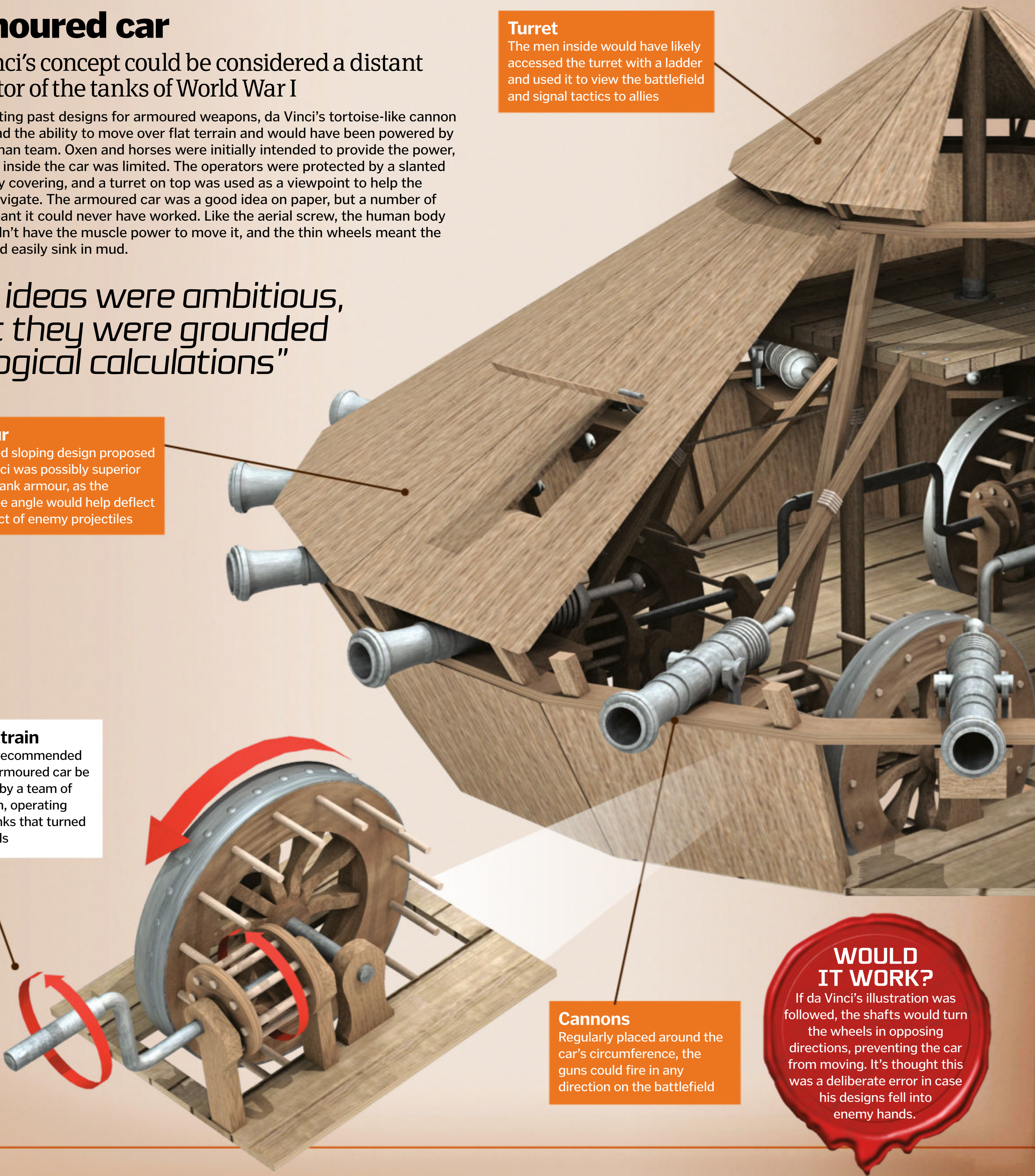
Da Vinci devised a number of military mechanisms that could have revolutionised the battlefield

Armoured car

Da Vinci's concept could be considered a distant ancestor of the tanks of World War I

Incorporating past designs for armoured weapons, da Vinci's tortoise-like cannon system had the ability to move over flat terrain and would have been powered by an eight-man team. Oxen and horses were initially intended to provide the power, but space inside the car was limited. The operators were protected by a slanted and sturdy covering, and a turret on top was used as a viewpoint to help the drivers navigate. The armoured car was a good idea on paper, but a number of issues meant it could never have worked. Like the aerial screw, the human body simply didn't have the muscle power to move it, and the thin wheels meant the tank would easily sink in mud.

> *"His ideas were ambitious, but they were grounded in logical calculations"*



Turret
The men inside would have likely accessed the turret with a ladder and used it to view the battlefield and signal tactics to allies

Armour
The plated sloping design proposed by da Vinci was possibly superior to WWI tank armour, as the 45-degree angle would help deflect the impact of enemy projectiles

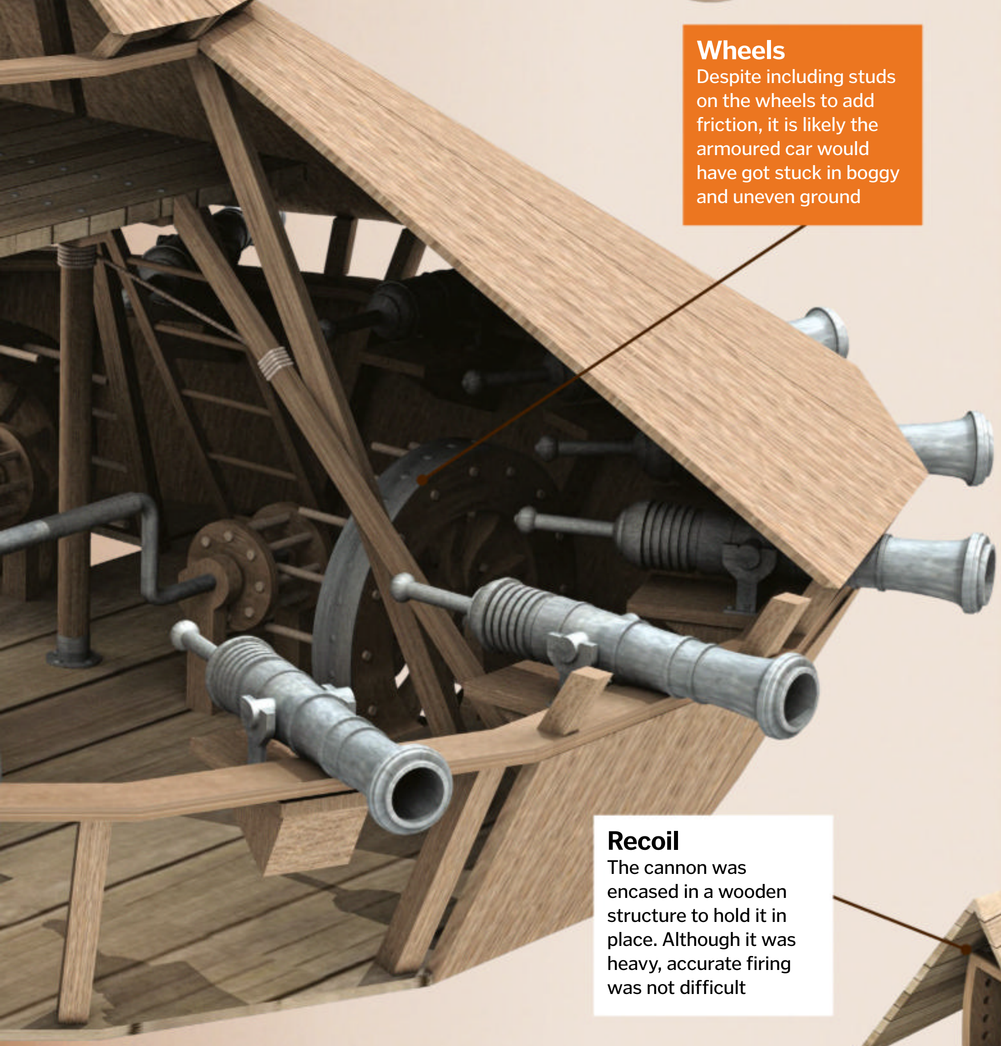
Power train
Da Vinci recommended that his armoured car be powered by a team of eight men, operating hand cranks that turned the wheels

Cannons
Regularly placed around the car's circumference, the guns could fire in any direction on the battlefield

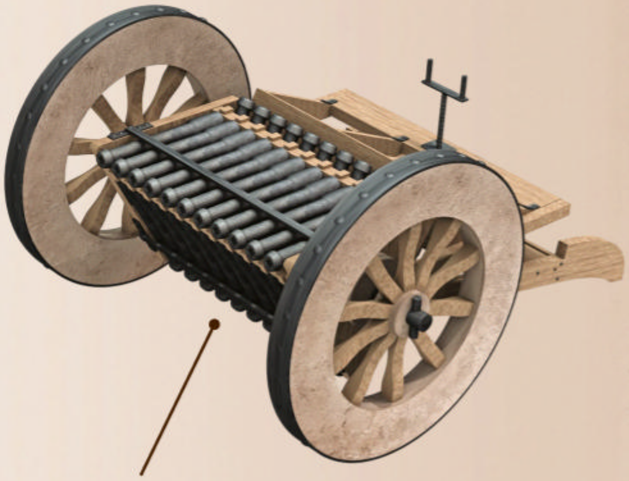
WOULD IT WORK?
If da Vinci's illustration was followed, the shafts would turn the wheels in opposing directions, preventing the car from moving. It's thought this was a deliberate error in case his designs fell into enemy hands.

The bombard
Another weapon that da Vinci depicts in his notebook is a bombard that launched fragmenting ammunition

Rain of metal
Once it was fired, the cannonballs would separate into several pieces, raining down lethal shards of metal on enemy infantry



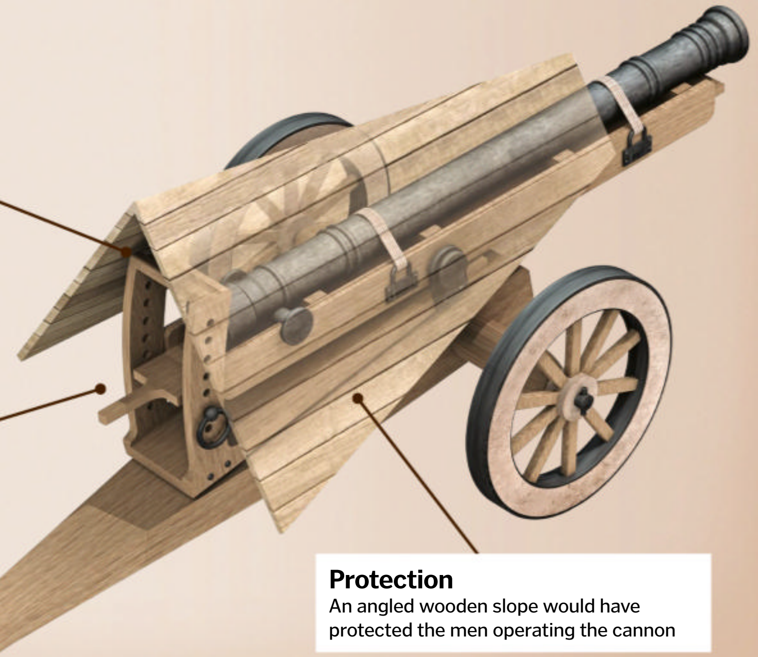
Wheels
Despite including studs on the wheels to add friction, it is likely the armoured car would have got stuck in boggy and uneven ground



Machine gun

A multi-barrelled weapon that could unleash rapid-fire projectiles at hordes of enemy soldiers

Cannons were important in Renaissance-era artillery. Da Vinci aimed to add maneuverability and extra firepower with his concept of a multi-barrelled war machine that could fire a dozen cannonballs at once. With wheels on its side, the portable muzzle-loaded cannon had a rotating body with up to three revolving rows of guns. One could fire while the other two cooled and were reloaded. The recoil would have been fierce, so the machine was equipped with a support bulkhead that held the main body in place. In one of da Vinci's sketches, the barrels are arranged in a fan shape to give the weapon a wider firing range.



Recoil
The cannon was encased in a wooden structure to hold it in place. Although it was heavy, accurate firing was not difficult

Protection
An angled wooden slope would have protected the men operating the cannon

Springald

A cannon intended to eliminate specific targets from the battlefield

The springald was an artillery device that existed before da Vinci, but like many of his other creations, he built upon the idea. His version had the ability to fire in many directions both horizontally and vertically. An elevating arc moved the springald up and down, and when the desired height was achieved, it was held in place by a cylindrical peg. It could then be aimed to the left and the right. Iron and stone cannonballs, and even metal-tipped arrows were fired from the breech-loaded cannon.

© Solgo

HYDRAULIC MACHINES

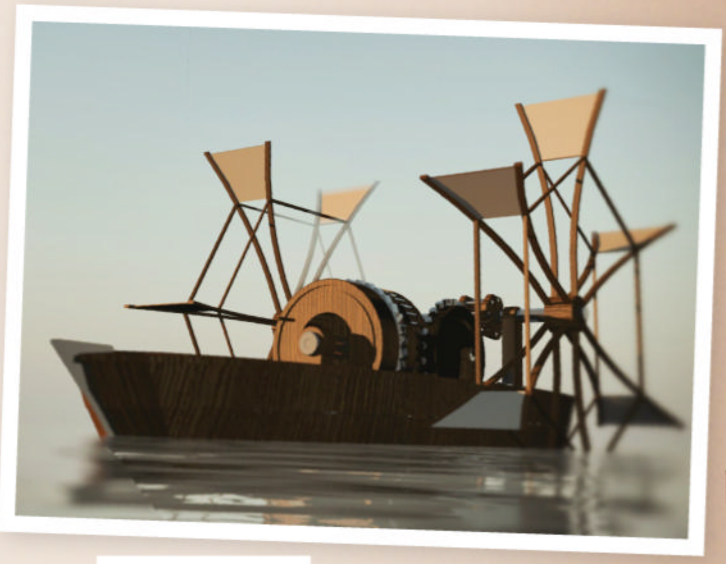
Da Vinci's notebooks feature several ideas for complex yet workable devices powered by water

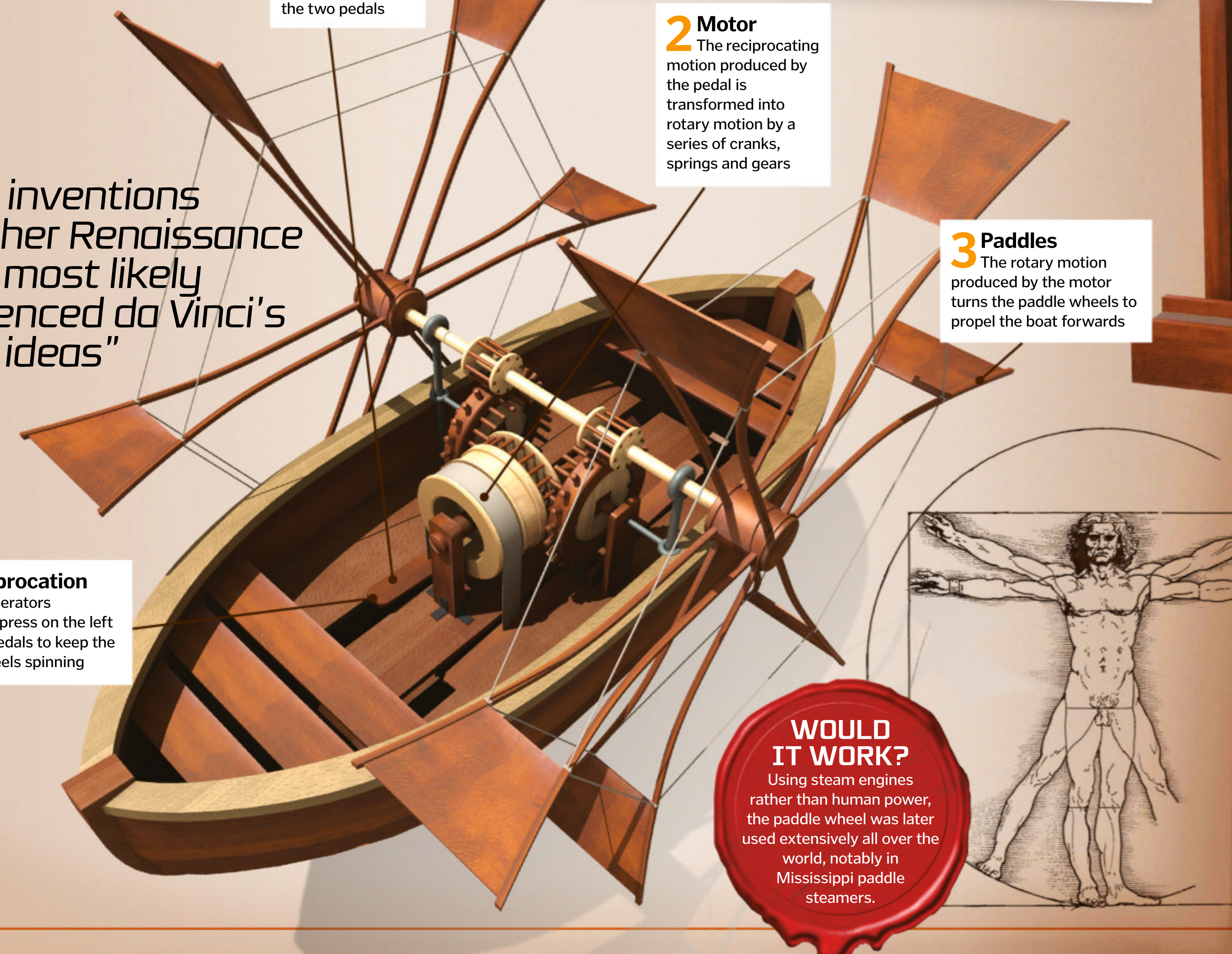
Paddleboat

This reciprocating-motion vessel was a huge advance on the oar-powered boats of the age

With the absence of internal combustion engines, boats and ships in the 15th century were powered either by wind or by oar. Writing between 1487 and 1489, da Vinci reasoned that a paddle-based mechanism that used reciprocating motion (repetitive back and forth movements) would be far more effective. By replacing the oars with paddle wheels, it would be easier for the boat to travel upstream.

The paddleboat wasn't an original da Vinci idea; Italian inventors Taccola and Francesco di Giorgio had both looked into the concept before, but this was the most realistic and workable proposal yet. The operators would push down on alternate foot pedals, which powered a reciprocating-motion system, which in turn was transformed into rotary motion to turn the paddle wheels and propel the boat forwards. The principle was the opposite of a water mill, with the machine moving the water rather than the water moving the machine.





1 Pedal The mechanism starts with the operator pushing down on one of the two pedals

2 Motor The reciprocating motion produced by the pedal is transformed into rotary motion by a series of cranks, springs and gears

3 Paddles The rotary motion produced by the motor turns the paddle wheels to propel the boat forwards

4 Reciprocation The operators alternately press on the left and right pedals to keep the paddle wheels spinning

> *"The inventions of other Renaissance men most likely influenced da Vinci's own ideas"*

WOULD IT WORK?

Using steam engines rather than human power, the paddle wheel was later used extensively all over the world, notably in Mississippi paddle steamers.

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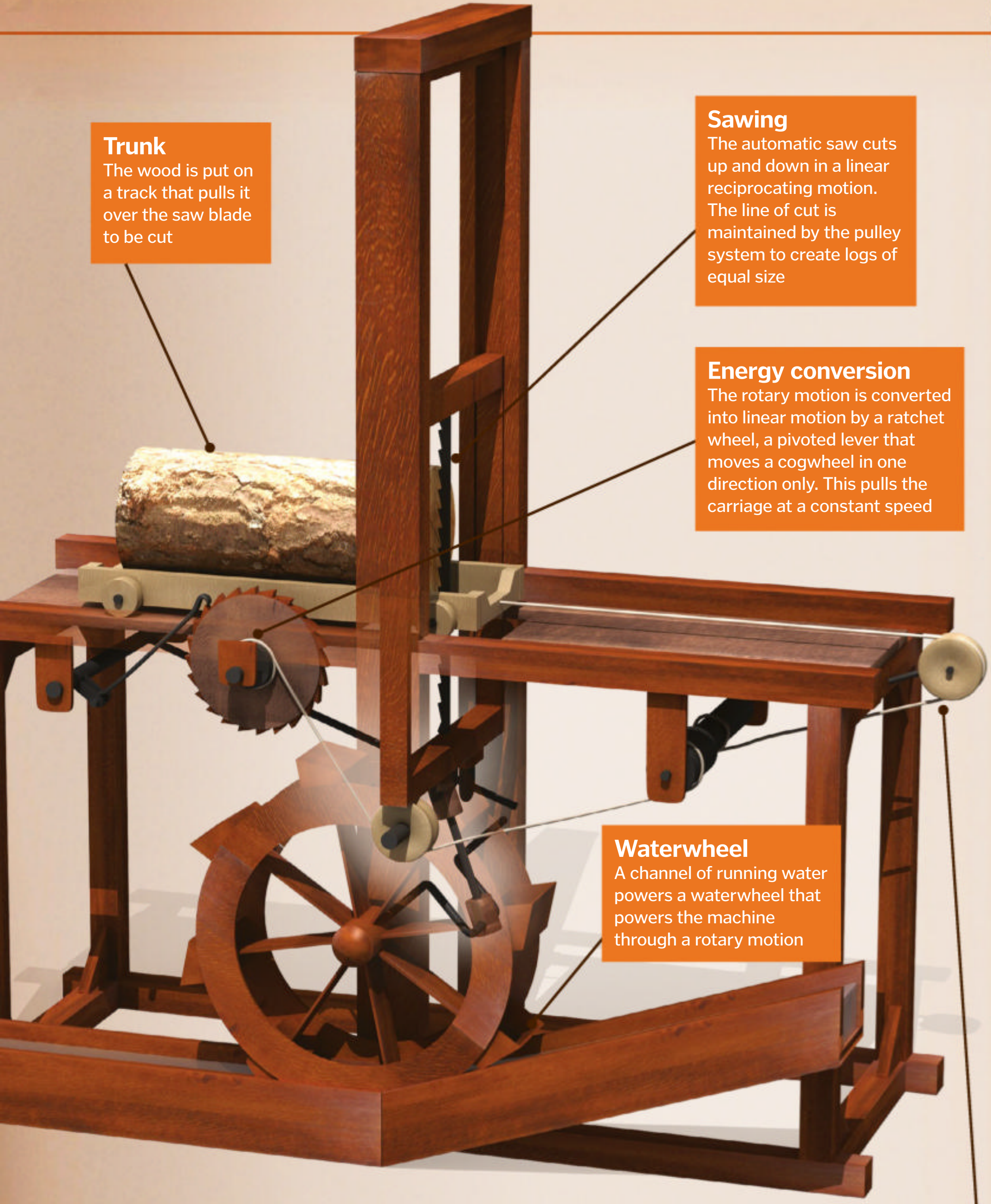
DID YOU KNOW? *Da Vinci was fascinated by water and used 64 different words in his notebooks to explain its movement*



Trunk
The wood is put on a track that pulls it over the saw blade to be cut

Sawing
The automatic saw cuts up and down in a linear reciprocating motion. The line of cut is maintained by the pulley system to create logs of equal size

Energy conversion
The rotary motion is converted into linear motion by a ratchet wheel, a pivoted lever that moves a cogwheel in one direction only. This pulls the carriage at a constant speed

Waterwheel
A channel of running water powers a waterwheel that powers the machine through a rotary motion

Pulleys
The mechanism is run using pulleys that gradually move the carriage as the wood is sliced

Mechanical saw

Another hydraulic invention that was designed to cut wood quickly and efficiently

Noted down circa 1478, da Vinci's mechanical saw was a rapid cutting device. The saw utilised the energy of a water mill to power the slicing of logs into wood. The wood would then be used for construction, particularly in war time, where it would be used to quickly build military bridges (these bridges were easy to transport and could be rapidly assembled across a body of water to allow troops to cross).

The saw's mechanism was relatively simple: a channel of running water turned a mill, and this rotary motion was transformed into linear reciprocating motion that powered the up and down sawing movement. The mechanism also powered pulleys and crankshafts that kept the log moving towards the saw. Like the paddleboat, the mechanical saw had been thought of before but not in this level of detail. Once again, da Vinci took a clever concept and improved it.

WOULD IT WORK?
The mechanical saw was one of da Vinci's least innovative but most workable concepts. Its automatic cutting system worked using the same principles as a standard water mill.

DA VINCI INVENTIONS USED TODAY

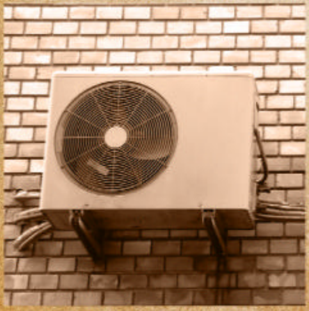
Ball bearings
First seen in a drawing in 1497, da Vinci based his idea on ancient Egyptians rollers that were used to transport huge stones up ramps to construct the pyramids.

Double hull
Da Vinci proposed the idea that a double hull would stop ships from sinking if its first was pierced by an enemy ship's ram, a weapon commonly used in naval battles.

Parachute
Da Vinci devised this combination of linen cloth and wooden poles 300 years before the first parachute test. His design was tested in 2005 and was proved to work.

ASIMO
HONDA

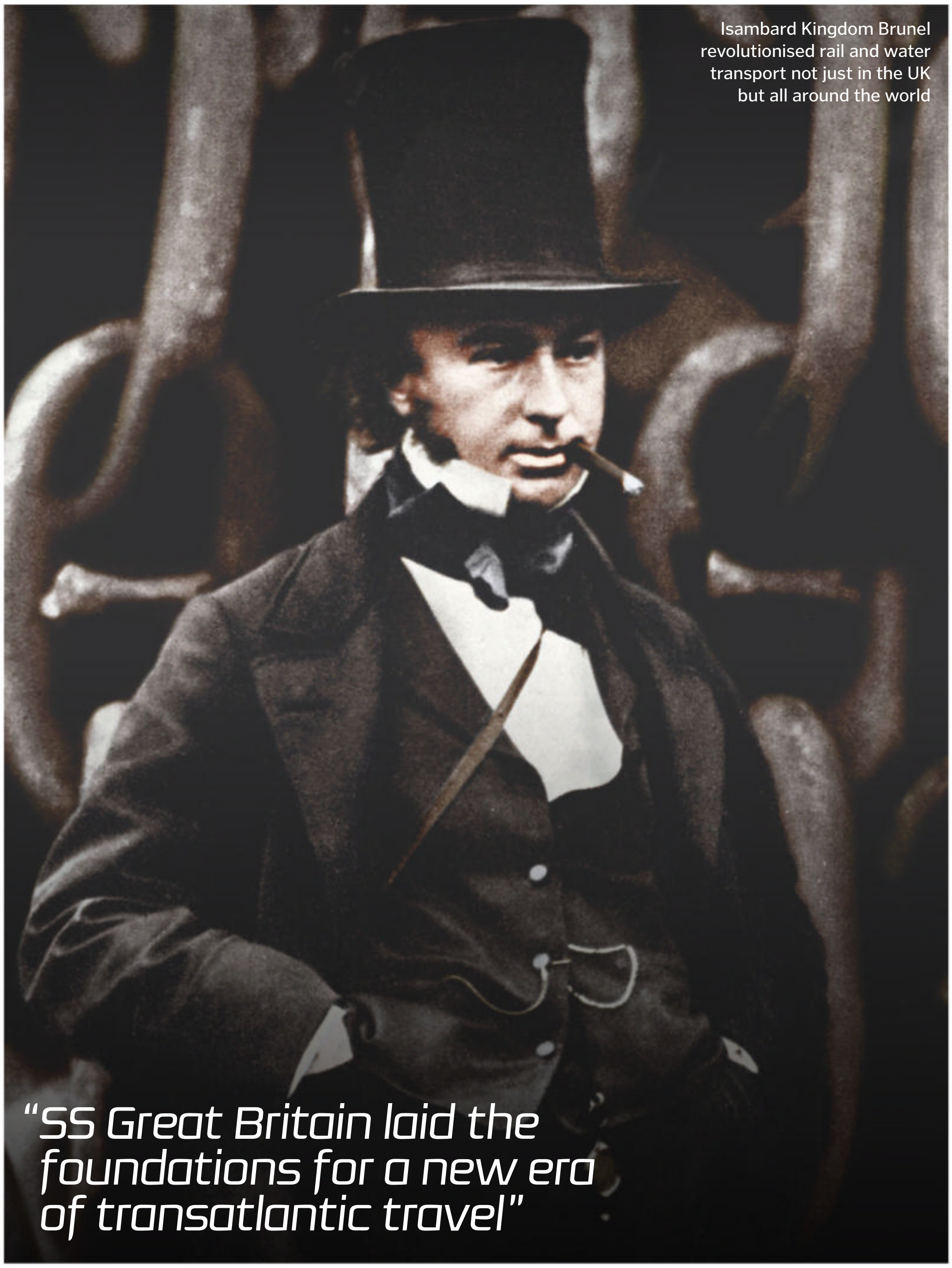
Robot
Using a system of pulleys, weights and gears, da Vinci's robot was a moving suit of armour that could move its limbs, turn its head and sit down and stand up.



Air conditioning
After being asked to help ventilate a boudoir, da Vinci developed a mechanical water-driven fan in 1500 that can be seen as a precursor to modern cooling systems.

Isambard Kingdom Brunel

Though not always successful, Brunel's designs revolutionised transport, and he is now remembered as one of the greatest engineers of all time



Isambard Kingdom Brunel revolutionised rail and water transport not just in the UK but all around the world

> "SS Great Britain laid the foundations for a new era of transatlantic travel"

While an era of progress, the Industrial Revolution was also a time of trial and error. Those leading the way in technological advances attempted to make huge leaps forward, often resulting in failure, but sometimes incredible success. One of the greatest of the innovators of this time was Isambard Kingdom Brunel, born at the start of the 19th century. His father, Marc, was a French civil engineer, and encouraged his son to learn arithmetic, scale drawing and geometry. At 16, he became a watchmaker's apprentice.

In 1824 Marc was appointed chief engineer of a project to construct a tunnel under the River Thames. He hired his son as an assistant engineer, who later became resident engineer. The project was fraught with disaster, witnessing several incidents of flooding, as well as financial difficulties. At one point the operation was halted for several years and the tunnel bricked up. It was eventually opened in 1843 and is still in use today as part of the London Overground network.

The project transformed the young Brunel into a full-fledged engineer. In 1830 he entered a competition to design a bridge that would span across the River Avon in Bristol, and although rejected initially, he eventually persuaded the panel to appoint him as project engineer. Work on the Clifton Suspension Bridge commenced in June 1831, but just four months later the Queen Square riots drove investors away. Once again a project ground to a halt.

In 1833 Brunel was made chief engineer of the Great Western Railway, which would run from London to Bristol. It was then that he developed one of the most controversial ideas of his career – to use a 2.1-metre gauge (distance between the tracks) rather than the standard 1.4-metre gauge. He believed that this would allow the trains to run at much higher speeds, as well as provide a more stable and comfortable journey without as much rocking back and forth. For the

A life's work

Brunel made his mark on history – but what were the defining moments in this innovator's career?

1806
Isambard Kingdom Brunel is born in Portsmouth, UK, to French civil engineer Marc Isambard Brunel and Sophia Kingdom.

1827
Brunel is appointed resident engineer of the Thames Tunnel project in London, taking over from his father.

1830
He enters a competition to design a bridge to span the River Avon and is awarded first place.

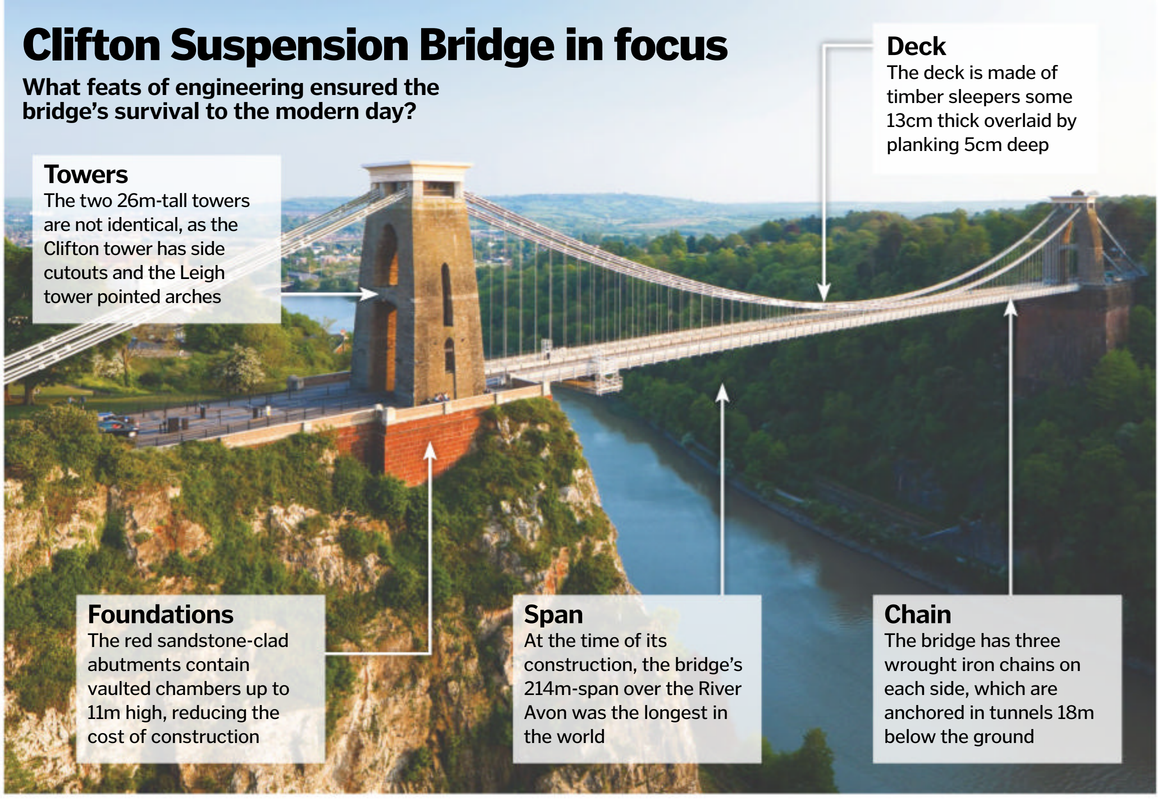
1831
Work on the Clifton Suspension Bridge begins but financial difficulties bring the project to a halt.

1833
Brunel becomes chief engineer of the Great Western Railway, developing his idea for a wider track.

DID YOU KNOW? *Brunel University in Uxbridge, London, established in 1966, is named after Brunel*

Clifton Suspension Bridge in focus

What feats of engineering ensured the bridge's survival to the modern day?



Towers
The two 26m-tall towers are not identical, as the Clifton tower has side cutouts and the Leigh tower pointed arches

Deck
The deck is made of timber sleepers some 13cm thick overlaid by planking 5cm deep

Foundations
The red sandstone-clad abutments contain vaulted chambers up to 11m high, reducing the cost of construction

Span
At the time of its construction, the bridge's 214m-span over the River Avon was the longest in the world

Chain
The bridge has three wrought iron chains on each side, which are anchored in tunnels 18m below the ground

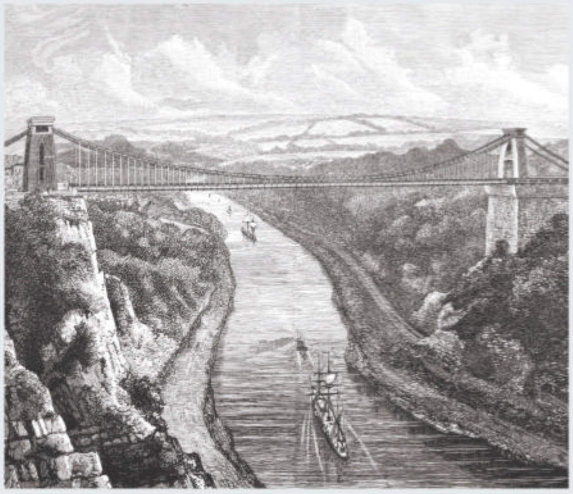
rest of his life the efficiency of this design was heavily contested.

But none could contest the efficiency of his Great Western Steamship, which transported passengers from Bristol to New York. It was thought a steamship would not be able to carry enough fuel for the trip and have room for cargo. However, it completed its maiden voyage in 15 days, with a third of its coal remaining. Brunel was also a fierce proponent of propeller-driven ships and incorporated a propeller on his second ship, SS Great Britain. Considered the first modern ocean-going ship, it was made of metal, powered by an engine rather than wind, and driven by a propeller rather than a paddle wheel. Indeed, this vessel laid the foundations for a new era of transatlantic travel.

Brunel's personal life was a series of ups and downs too. Many say the stress of the Great Western Railway led to his early death in 1859. Soon after it was decided all railways in the country should revert to using the standard gauge. However, funds were also raised to complete the Clifton Bridge, which was opened five years after Brunel's death and is still in use.

The big idea

The Clifton Suspension Bridge in Bristol spans 214m between two 26.2m towers, which at the time was the longest bridge span in the world. In its design of chains and rods, Brunel had made a near-perfect calculation of the minimal weight required to provide maximum strength. The abutments contain a honeycomb of chambers and tunnels, some of which are 11m high, which reduced the cost of construction without compromising strength.



Brunel trivia

1 French connection

During his teenage years, Brunel attended school in France, but surprisingly his application to the renowned French engineering school École Polytechnique was unsuccessful, owing to the fact that he was a 'foreigner'.

2 River party

In 1827, after several incidents of flooding, Brunel held a lavish banquet inside the Thames Tunnel to help convince people that it was perfectly safe.

3 Beating the competition

Brunel's submission to the Clifton Bridge competition was initially rejected by the judge, Thomas Telford, who instead put forward his own design for the bridge.

4 Flip of a coin

In 1843, while performing a magic trick for his children, a coin became lodged in Brunel's windpipe. In order to remove it, he was strapped to a board and turned upside down.

5 Commissioned by the lady with the lamp

In 1855 Brunel responded to a request from Florence Nightingale, known as nursing icon 'the lady with the lamp', to design a new hospital that would replace the unsanitary British Army Hospital in Scutari, Turkey, which he did successfully.

1838
The Great Western Steamship sails from Bristol to New York in just 15 days.

1843
The Thames Tunnel is opened to the public and the propeller-driven SS Great Britain is launched.

1852
Brunel's design for Paddington Station is constructed.

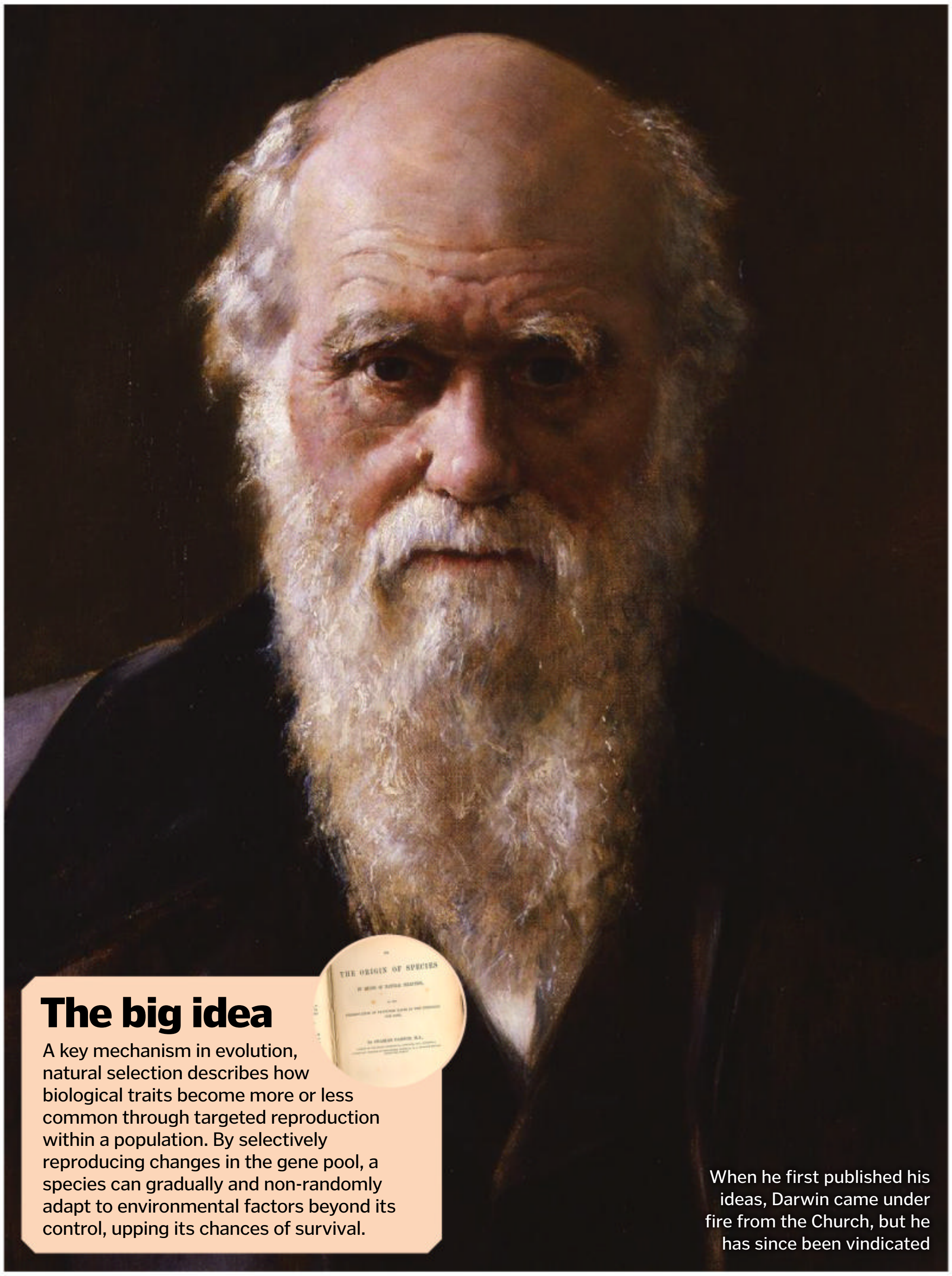
1859
Brunel dies on 15 September, ten days after suffering a stroke.

1864
The Clifton Suspension Bridge is finally completed as a tribute to Brunel by the Institute of Civil Engineers.

© Alamy; National Maritime Museum

Charles Darwin

The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time



When he first published his ideas, Darwin came under fire from the Church, but he has since been vindicated

Charles Robert Darwin was an English naturalist renowned today for his theories of evolution and natural selection, both of which were introduced in his seminal work *On The Origin Of Species*. The book was both lambasted and celebrated on its publication. Early controversy stemmed from its apparent undermining of religious scripture, but it would become one of the most influential works of Western society, with the entire field of evolutionary studies arising from it.

Though *On The Origin Of Species* was published in 1859, Darwin originally conceived of evolution by natural selection shortly after an around-the-world tour starting in 1831. He embarked on the journey to expand his newly formed interest in natural history, spending the trip collecting specimens and analysing many interesting species, when not suffering from seasickness. During the expedition on HMS Beagle he collected over 5,436 skins, bones and carcasses of various creatures. His experiences and findings led him to question many of the accepted beliefs at the time concerning life's origins.

In 1838 he pinned down his theory of natural selection proper – see 'The big idea' boxout for more details. Over the next 20 years, he continued to refine it until he received a letter from fellow British naturalist Alfred Russel Wallace proposing a collaboration. The fact that both men shared the same ideas led to the joint publication of their research. While Wallace's hypotheses on the subject were detailed, his hands-on research was lacking and Darwin's extensive fieldwork won out, with history since attributing the theory largely to the latter.

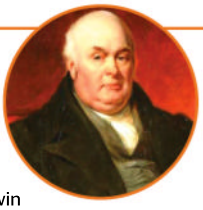
The publication of *On The Origin Of Species* the following year was therefore a landmark moment for Darwin – and for science as a

The big idea

A key mechanism in evolution, natural selection describes how biological traits become more or less common through targeted reproduction within a population. By selectively reproducing changes in the gene pool, a species can gradually and non-randomly adapt to environmental factors beyond its control, upping its chances of survival.

A life's work

Famous for describing the evolution of humanity, we chart Darwin's own evolution through the 19th century



1809
Charles Darwin is born in Shrewsbury, England. His parents are Robert (above) and Susannah Darwin.

1818
In June, Darwin goes to Shrewsbury School as a boarder, where he studies for seven years.

1825
Darwin signs up for medical courses at the University of Edinburgh with elder brother Erasmus.

1827
He is admitted to Christ's College Cambridge to study not science but divinity.

1831
Accepts an offer to join a voyage on HMS Beagle which sets sail on 27 December.

DID YOU KNOW? *From a young age Darwin collected and performed experiments on stones and beetles with his brother*

HMS Beagle spent just five weeks in the Galápagos Islands, but that was long enough for Darwin's research purposes

whole. To a degree it was a bringing together of various ideas that had already been mooted by other biologists but unproved. While Darwin did not supply concrete evidence for evolution, the work's lucidity and logic meant that, towards the end of the 1870s, the scientific community, and society as a whole, had accepted his views.

Darwin followed up this groundbreaking title in 1871 with *The Descent Of Man, And Selection In Relation To Sex*, where he applied his own evolutionary theory specifically to human's evolution from apes. This book was incredibly popular from the word go, with a reprint ordered within just three weeks of publication. Three months after its release, 4,500 copies had been sold – a testament to his rising fame.

Darwin died on 19 April 1882 from heart disease and, after a request by his colleagues, was granted a state funeral at Westminster Abbey, buried alongside other famous scientists John Herschel and Isaac Newton.

Although some claim the significance of Galápagos finches to Darwin's theories has been overblown, more recent research indicates they are a good example of micro-evolution

Perhaps the most famous resident of the Galápagos, the giant tortoise

> *"The publication of* On The Origin Of Species *was a landmark moment for Darwin – and for science"*

Five facts: Charles Darwin

1 Family guy

Darwin had ten children, though two died while still young. Three of his sons went on to become members of the Royal Society themselves.

2 On the money

Darwin is commemorated in the UK with his portrait printed on £10 banknotes, alongside a hummingbird and the ship HMS Beagle.

3 School of thought

The school that Charles Darwin attended as a boy, Shrewsbury School, still exists, but it is no longer in the same building, which has since become a library.

4 Name gets around

Due to Darwin's great achievements in the field of natural history, more than 120 species and nine different genera have been named in his honour to date.

5 No sea-lover

HMS Beagle took five years to circumnavigate the globe, but Darwin only spent 18 months on board. From the day it set sail, he was afflicted with terrible seasickness throughout.

1836
Lands back in England on 2 October and returns home to Shrewsbury.

1839
Marries Emma Wedgwood and has his first of ten children.

1858
Receives a letter from Alfred Russel Wallace who shares many of his ideas about the theory of natural selection.

1859
Publishes *On The Origin Of Species By Means Of Natural Selection, Or The Preservation Of Favoured Races In The Struggle For Life.*

1864
Receives the Copley Medal, the highest accolade from Britain's Royal Society.

1882
Darwin dies, aged 73, and is buried at Westminster.

© Mike Cornwell

The Wright brothers

These siblings played a pivotal role in the evolution of powered flight and radically altered the path of aviation history

Wilbur (right) and Orville attend the Belmont Park Aviation Meet, NY, in 1910

Wilbur and Orville Wright are two of history's most famous aviation pioneers who, through a series of experiments in the late-19th and early-20th centuries, created the first controllable, powered, heavier-than-air aircraft. Named the Wright Flyer, the plane was the culmination of over a decade's worth of research and trials that saw the brothers progress from custom-built kites, through to gliders and finally on to engine-powered aeroplanes. Together these talented siblings are generally credited with launching the age of powered flight.

Wilbur and Orville Wright were the sons of Milton Wright, an ordained minister of the Church of the United Brethren in Christ, and Susan Catherine Koerner Wright. The family lived in various locations including Richmond, Indiana; Cedar Rapids, Iowa; and Dayton, Ohio – the latter for the majority of the brothers' lives. Orville later explained that his father had encouraged both of them from an early age "to pursue intellectual interests and to investigate whatever aroused curiosity."

This encouragement led Orville and Wilbur into a diverse range of interests and expertise including printing, bicycles – which the pair sold and repaired for several years – and the construction of various machines from wood and metal. Both engineers and inventors, the brothers became well known for their academic and practical application of modern engineering, with Wilbur especially spending much time in his father's and public libraries.

One of their heroes was German gliding pioneer Otto Lilienthal, who up until his death in 1896 had built and flown a series of aircraft to varying degrees of success. His death, however – which was the result of a glider crash – oddly spurred the brothers' interest in flight, with them writing to the Smithsonian Institution for suggestions on other aeronautical manuscripts. One of the museum's recommendations was the engineer Octave Chanute, a leading authority on aviation and civil engineering at the time.

With Chanute's help the brothers began conducting a number of aeronautical experiments. Crucial to their approach was the focus on control of the aircraft, advancing previous designs that could only fly in a straight line by introducing a helical twist across the wings in either direction. The brothers tested this configuration in 1899 and, after discovering that it allowed the acute control of a kite, began working on a full-scale model: the first Wright Glider. It was tested in October 1900 at Kitty Hawk, North Carolina, where although lifting off the ground, it produced disappointing results.

The Wright brothers refined their glider and tested it in 1901, then again in October 1902 after spending the summer undertaking a vast series of tests into more efficient wing designs. This third model was the breakthrough, with the glider performing exactly as predicted. The pair – who each piloted the glider in turn – racked up almost 1,000 flights between them over a two-month period, covering distances at Kitty Hawk of up to 190 metres.

Realising they had cracked both the aerodynamic and control issues that all of

The big idea

Prior to the Wright brothers' successful flight (pictured below), many other scientists and engineers had dreamed about and, to varying degrees of failure, attempted to build machines that could not only defy gravity, but do so in a controlled manner. Their failures left the idea of a non-dirigible method of flight as mere fancy, with materials, aerodynamics and energy supplies all seeming insurmountable obstacles.

What is testament to the Wright brothers' expertise is that they addressed each one of these issues with their aircraft in turn, solving in years what countless minds had failed to address in centuries. Examples include the testing of hundreds of wing designs in a custom-built wind tunnel to determine which shape best granted lift, designing and building their own four-cylinder internal combustion engine that was adapted for air travel, and recognising that propeller blades could be understood as rotary wings.

A life's work

The main milestones that led to the Wright Flyer taking off…

1867
Wilbur is born, with Orville arriving four years later.

1869
The Wright family move to Dayton, OH, due to the father's work commitments.

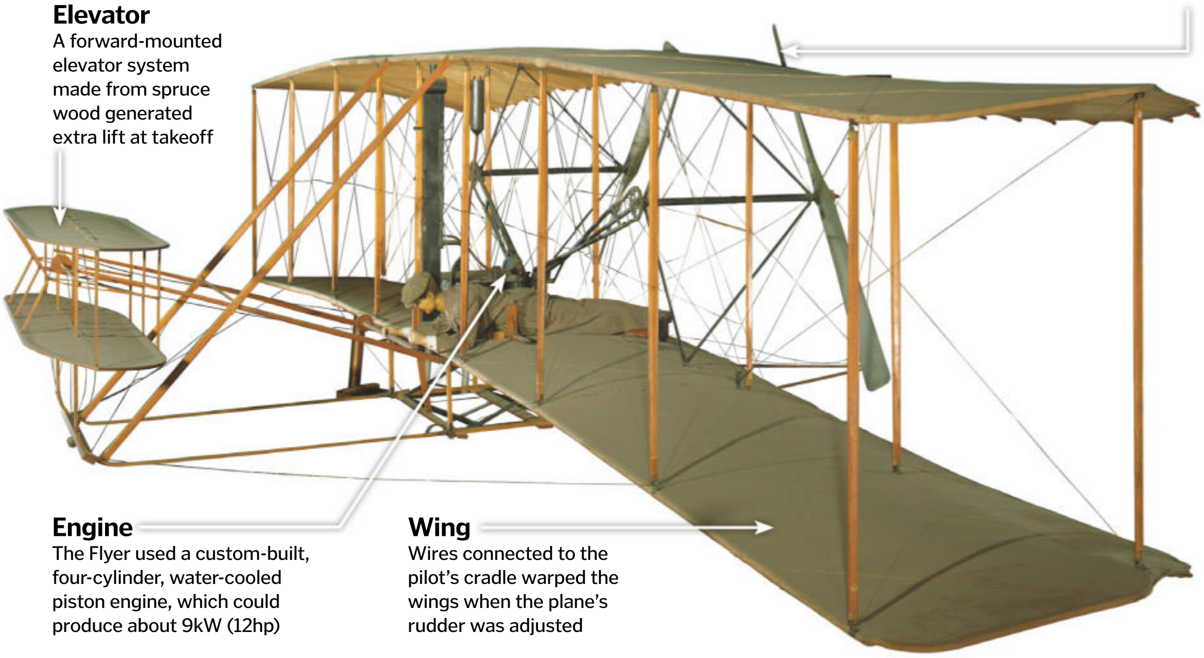
1892
Both brothers team up to open a bicycle repair shop. They begin building bikes a few years later.

1900
Years of research lead to the brothers testing the Wright Glider (right), an unpowered biplane with a forward elevator for pitch control.

DID YOU KNOW? *Orville Wright was a troublemaker as a child, and once was expelled from elementary school*

The Wright Flyer in focus

Take a closer look at the pinnacle of the Wright brothers' aviation careers



Elevator
A forward-mounted elevator system made from spruce wood generated extra lift at takeoff

Propeller
Two large propellers were driven by a sprocket chain drive, granting the Flyer a small amount of thrust

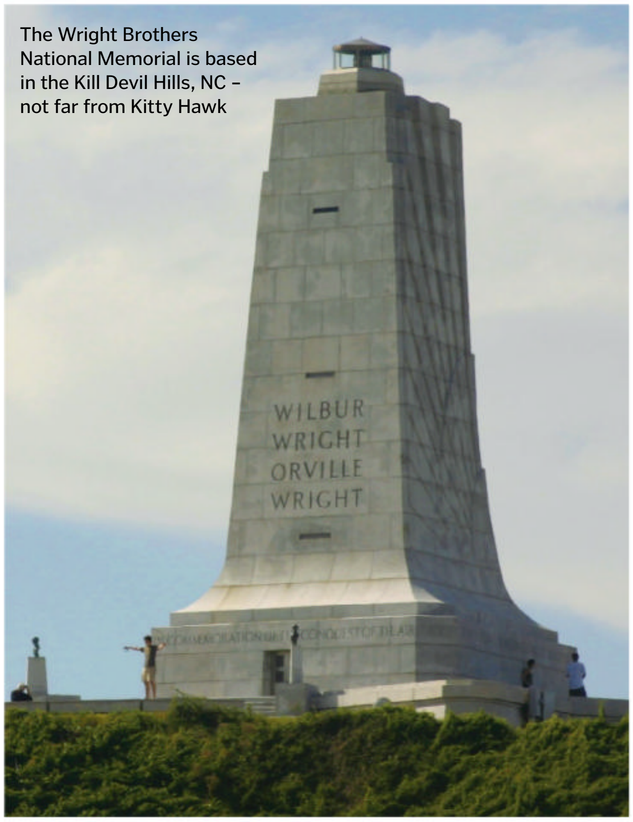
Engine
The Flyer used a custom-built, four-cylinder, water-cooled piston engine, which could produce about 9kW (12hp)

Wing
Wires connected to the pilot's cradle warped the wings when the plane's rudder was adjusted

their predecessors had struggled with, the two brothers turned their attention to a power plant for the glider. In 1903 they built their own four-cylinder internal combustion engine and returned to Kitty Hawk to trial it. Unfortunately the first attempt ended in the engine stalling during takeoff and the front of the plane getting damaged, but after a couple of repairs, the second flight ended in resounding success.

Lifting off at 10.35am on 17 December 1903, the Wright Flyer flew 36 metres, then 53 metres, followed by 60 metres before finally achieving a distance of 259.7 metres. This series of flights heralded a new era of aviation and propelled the Wright brothers and their aeroplane to worldwide fame.

> *"The brothers became well known for their academic and practical application of modern engineering"*



The Wright Brothers National Memorial is based in the Kill Devil Hills, NC – not far from Kitty Hawk

Five facts: Wright bros

1 No college

Wilbur and Orville were the only members of the Wright family who didn't attend college. Orville spent the years learning the printing trade, while Wilbur helped out at the local church.

2 Lifelong bachelors

Neither of the Wright brothers married throughout their lives. Wilbur is recorded as once saying that he "did not have time for both a wife and an airplane."

3 Child's play

In their later lives, the Wright brothers attributed their fascination with flying machines to a small toy helicopter which their father had brought home one day from his travels.

4 Luminaries

Both of the brothers extensively catalogued their aviation experiments on paper, leading to Wilbur Wright delivering an official talk at the highly prestigious Western Society of Engineers in Chicago in 1901. The speech he gave was entitled, fittingly, 'Some Aeronautical Experiments'.

5 Hobby to business

In 1909 the Wright Company was incorporated with Wilbur as president and Orville as one of two vice-presidents. Orville sold the company three years after Wilbur's death in 1912.

© Thinkstock; Getty

1903
The brothers successfully fly the Wright Flyer in sustained flight at Kitty Hawk, NC. Its fourth flight covers 259.7 metres in just 59 seconds.

1909
The Wright Company sells the first-ever military aircraft, the Wright Military Flyer (right), to the US Army Signal Corps.

1912
Wilbur dies of typhoid fever on 30 May at 45 years old.

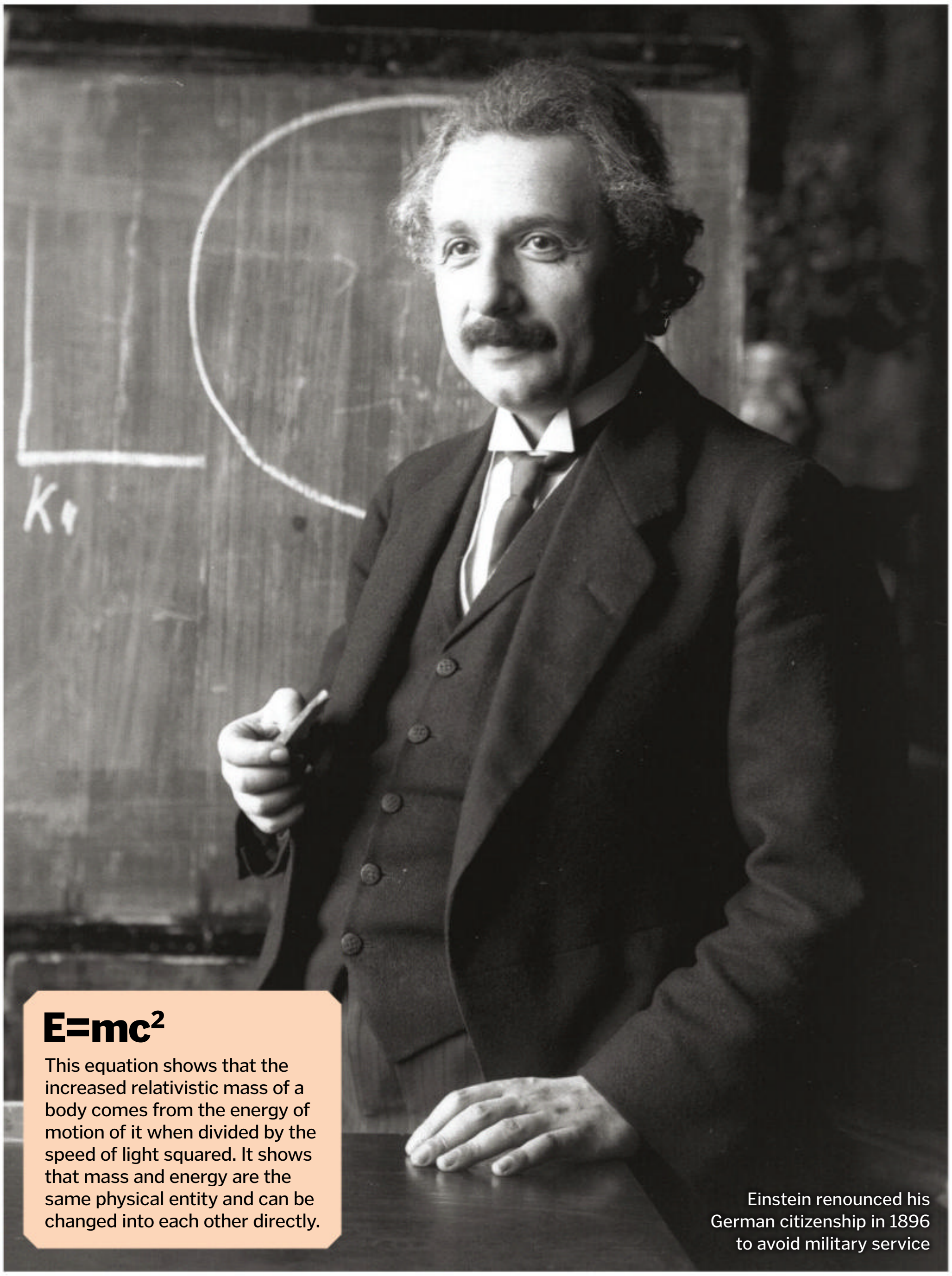
1915
Orville ends his leadership of the Wright Company by selling his shares to a group of financiers.

1920
Orville joins the board of the National Advisory Committee for Aeronautics – a precursor to NASA.

1948
Orville suffers a heart attack on 27 January and dies three days later in Dayton, OH, aged 76.

Albert Einstein

The foremost scientist of his age, Einstein is considered the most influential physicist of all time



E=mc^2

This equation shows that the increased relativistic mass of a body comes from the energy of motion of it when divided by the speed of light squared. It shows that mass and energy are the same physical entity and can be changed into each other directly.

Einstein renounced his German citizenship in 1896 to avoid military service

Albert Einstein was born on 14 March 1879, in Ulm, Germany. He is considered the most influential physicist of the 20th century, formulating both the theories of special and general relativity, concepts that still underpin much in the fields of physics and astrophysics today. In 1921 he was awarded the prestigious Nobel Prize in Physics for his explanation of the photoelectric effect – a process where electrically charged particles are released from a substance when exposed to electromagnetic radiation.

Einstein's first real contact with science came when he was a young boy, instigated by his intrigue with his father's compass. Confused by the invisible forces that seemed to be acting upon the needle, he went through his early years fascinated by such forces. Spurred on by reading the work of Aaron Bernstein, which introduced him to the concepts of electricity and light, Einstein dedicated his later teenage years to the nature of light, writing a scientific paper entitled 'The Investigation Of The State Of Aether In Magnetic Fields'.

Despite a great love for the sciences, Einstein had a troubled education. He skipped classes while attending the Swiss Federal Polytechnic School, and his father's failed business led to much disruption, with Einstein having to move frequently. This led to a period where he was forced to take a position at the Swiss patent office in Bern, a role significantly less prestigious than his desired doctorate.

In hindsight, though, the position at the patent office was ideal, as the work left much time for him to theorise on the properties and nature of light. Then, suddenly, in 1905 Einstein made a breakthrough, starting what is now termed his 'miracle year'. In that time he published four papers: the first on the photoelectric effect, the second on the existence of atoms, the third introducing the

A life's work

We chart Einstein's phenomenal journey to becoming the most influential physicist

1879

Einstein is born on 14 March in Ulm, Germany.

1896

After avoiding military service, Einstein enrolled in a four-year mathematics and physics teaching course in Zurich.

1905

Einstein released four papers on the photoelectric effect, Brownian motion, special relativity and the equivalence of matter and energy.

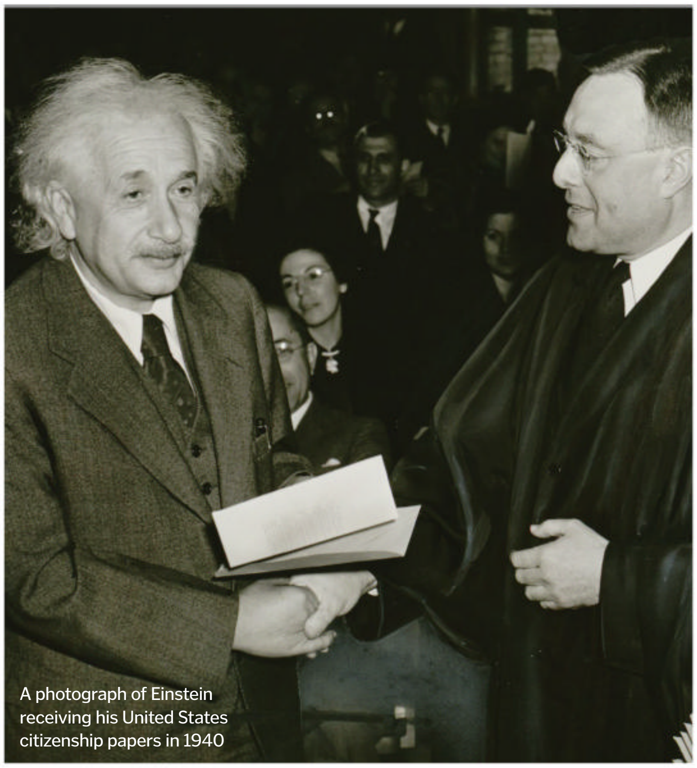
1906

Einstein receives a doctoral degree from the University of Zurich.

1908

He becomes lecturer at the University of Bern.

DID YOU KNOW? *Einstein had an illegitimate daughter, who was born in 1902*


A photograph of Einstein receiving his United States citizenship papers in 1940

Einstein's former summer home in Germany was confiscated by the Nazis in 1933

mathematical theory of special relativity and the fourth on the theory of relativity. Famously, Einstein published the last paper almost as an afterthought, despite it containing the key equation for which he is famous: $E=mc^2$.

At first the scientific establishment ignored Einstein's papers. Fortunately, though, they caught the attention of the foremost scientist of the age: Max Planck, the founder of quantum theory. Through Planck, Einstein became a respected member of the international community, attending the prestigious Solvay conferences and being offered important positions at Europe's foremost universities.

After completing his theory of general relativity in November 1915, Einstein's work was interrupted by World War I. Being a life-long pacifist, Einstein opposed the war and spoke frequently on its folly. After its conclusion, Einstein toured the world, but his period away from Europe was soon to be made permanent, with Einstein fleeing Nazi Germany in 1933. He settled in America and was granted US citizenship in 1940.

While in America, though he was not immediately convinced that an atomic bomb was possible, Einstein had encouraged the US government, including personally writing to President Roosevelt, to research nuclear chain reactions using uranium in response to German advances in the field. He did not work directly on the project to build a bomb, despite it being heavily based on his own work. According to reports, Einstein was on vacation when the first atomic bomb was dropped on Hiroshima, Japan. This action and its aftermath led to him undertaking anti-nuclear campaigns and lectures for the rest of his life.

Einstein's later years saw him pioneer numerous key theories including wormholes, multi-dimensional models and the possibility of time travel, as well as discovering his unified field theory. The latter was to be an all-embracing theory that would unify the forces of the universe and physics into one framework. The theory was never completed, however, with Einstein dying of an aortic aneurysm in 1955 before being able to finish his work.

Five facts: Einstein

1 Boy of few words

According to reports, Einstein seldom spoke as a child and when he did, it was very slowly. Accounts state he did this until he was nine.

2 Point of inspiration

Einstein's interest in science was reportedly sparked by his father's compass. At the age of five he thought there must be some force in the apparently empty space that acted on the needle.

3 Slow to start

Einstein did not receive outstanding grades while at school, and when he left he flunked the entry exam for the polytechnic institute in Zurich. Instead he went to work in the Swiss patent office first.

4 Nuclear pacifist

Einstein was a pacifist and while initially supporting the use of atomic weapons as a deterrent, he later chose to campaign for nuclear disarmament and world peace.

5 The man with two brains

After his death in 1955, Einstein's brain was removed for preservation by Thomas Stoltz Harvey in an attempt to discover what made him so intelligent.

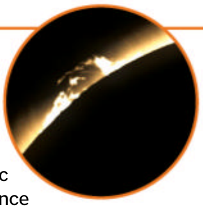
> *"In 1905 Einstein made a breakthrough, starting his 'miracle year'"*

1911
Einstein moves to Prague, where he acts as professor at the Karl-Ferdinand University.

1912
Einstein moves back to Switzerland, taking up a professorship at his alma mater, the Swiss Federal Institute of Technology in Zurich.

1915
Einstein completes his general theory of relativity.

1919
A solar eclipse provides dramatic observable evidence that his general theory of relativity is correct, making him a worldwide celebrity.



1921
16 years after its publication in 1905, Einstein wins the Nobel Prize in Physics for his work on the photoelectric effect.

1933
Einstein and his family flee from Nazi Germany to settle in the United States. He works at the Institute of Advanced Study at Princeton.

© Roland zh; NASA

PREHISTORIC

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How did an entire tribe of giant reptiles disappear from the face of the Earth?

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Discover life forms that lived millions or billions of years ago before being turned to stone

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Uncover the lost world and giant beasts of frozen Earth

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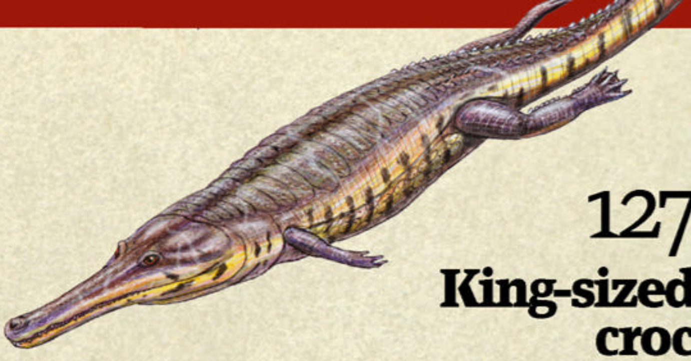
The enormous ancient predators that ruled the land, seas and skies



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King-sized croc

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© Alamy; SPL; Thinkstock; Mariana Ruiz; DiBGD

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LAST DAYS OF THE DINOSA

DID YOU KNOW? *Some scientists have posited another theory for the KT extinction – a prolonged period of volcanism*

AURS

How did an entire tribe of giant reptiles disappear from the face of the Earth?

In 1677, English naturalist Robert Plot came face-to-face with a thigh bone belonging to an animal one and a half times his height. He thought the monstrous femur belonged to a giant. Since then, enormous bones have shown up in rocks around the world, but the creatures that they belonged to are nowhere to be seen.

From the spike-thumbed iguanodons of England to the feathered microraptors of China and the iconic tyrannosaurs of the United States, dinosaurs ruled every corner of our planet, but between 66-64 million years ago they completely disappeared. The so-called KT extinction marks the transition between the Cretaceous and Tertiary periods of geological history.

During this catastrophic period, almost three-quarters of life on Earth withered away. Ammonites and belemnites disappeared from the oceans, along with dozens of species of nanoplankton, two entire groups of clams and many of the relatives of modern starfish, sea urchins, brittle stars and sea cucumbers. The ocean's top predators, the mosasaurs, also vanished. Winged pterosaurs went missing from the skies, and flowering plants died in their thousands, leaving behind a landscape dominated by ferns.

In 1980, Nobel Prize-winning American physicist, Luis Alvarez, and his son Walter noticed something unusual in the geological record. At around the time of the KT extinction, there was a band of the brittle, white transition metal, iridium. Usually rarer than gold, spikes of this unusual element appear in more than 100 places across the globe. The most likely explanation was an asteroid impact.

Iridium might be rare on our planet, but it's common in space rock. If an asteroid had collided with Earth, it could have kicked the metal into the atmosphere. As the dust settled, this would have formed a band in the rocks, marking the time of the impact.

At the level of this band there is also evidence of shocked quartz; a type of rock with distinctive microscopic features that form under intense pressure. There are also spheres of glass, made when molten rock is thrown up into the atmosphere and solidifies before it falls back to the ground. And there are vast quantities of soot, which could signal large-scale forest fires caused by burning debris from an extraterrestrial impact. Traces of the asteroid are greatest in North America. In Haiti there is a thick band of clay filled with glass spheres, and in the Gulf of Mexico tumbled rocks hint at an enormous tsunami, which could have been caused by an asteroid slamming into the planet.

To cause this level of destruction, the asteroid would have had to have been more than ten kilometres wide and travelling so fast that it would have gouged a 100-kilometre-wide hole in the surface of the planet. It should have left an enormous crater, but the impact site was nowhere to be seen, and not everyone was convinced by the theory.

Earth was already undergoing a climate crisis; sea temperatures were rocking up and down, and water levels were rising and receding. What's more, asteroids aren't the only source of iridium, and extraterrestrial impacts aren't the only way that ash gets into the atmosphere. Even shocked quartz and glass spheres can be made by something other than an asteroid. All of these features could also be explained by volcanoes, and around the time the dinosaurs disappeared, there were some monumental eruptions.

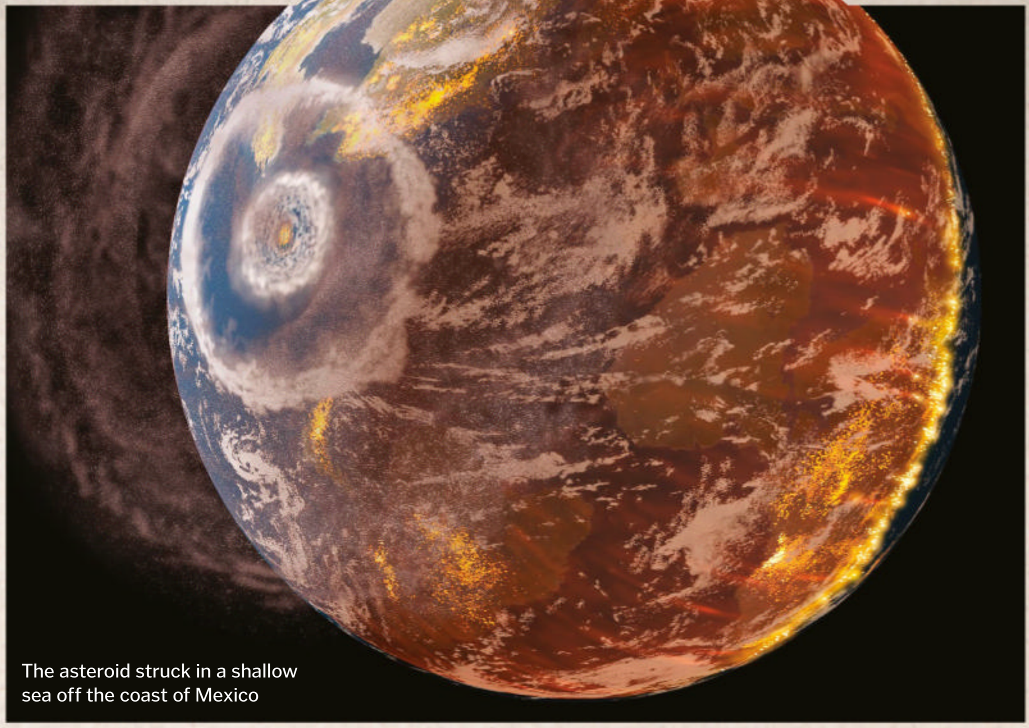
At that time, India was an island sitting on top of a volcanic hot spot. Bubbles of hot rock were rising from the Earth's mantle, which, unlike the crust, contains high levels of iridium. The magma poured out onto the surface, depositing more than 1 million cubic metres of new rock and forming vast lava plains now known as the Deccan Traps. As this happened, ash, sulphur and metal would have billowed and plumed into the air, potentially blocking out sunlight.

Both sides claimed the same evidence for their explanation of the trigger that caused the dinosaurs' demise, and without an actual impact crater, the Alvarez hypothesis had some gaps, but in 1990 geoscientist Alan Hildebrand found the smoking gun. Buried in a shallow sea off the coast of Mexico, there was a 180-kilometre-wide hole with strange gravity and an unusual magnetic field. It contained igneous rock, shocked quartz, spheres of glass and breccias – structures made from crushed rock glued together by mineral cement. It looked like the debris of an asteroid impact.

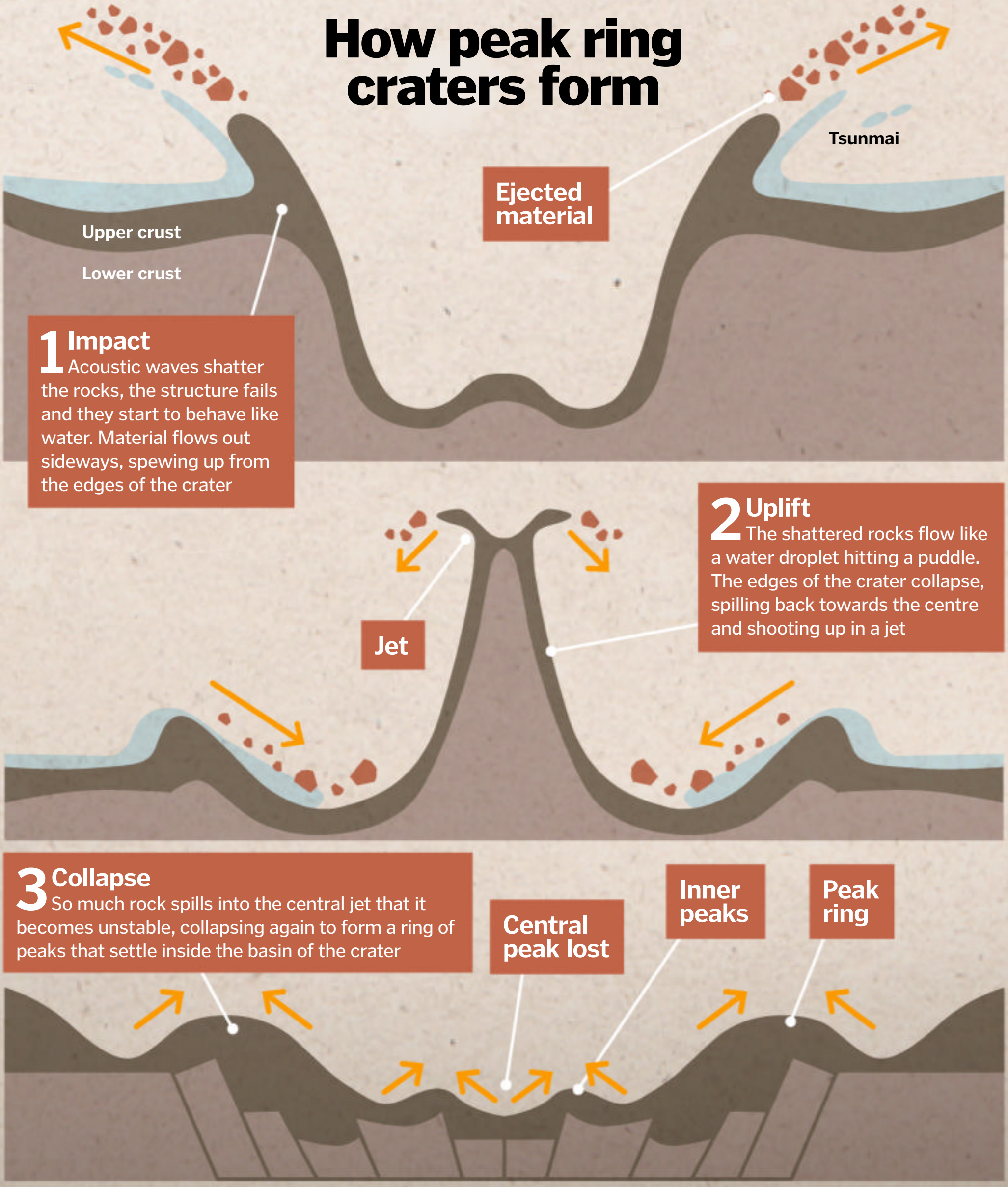
From the shape of the crater, it appears the asteroid came in at an angle, skidding debris up towards North America. The rock would have been fractured by intense vibrations, shooting molten debris into the air, and the thermal shock would have been so intense that everything within sight of the impact would have been totally obliterated.

What followed would have been an earthquake of a magnitude unmatched by even the most powerful in recorded history. Vast tsunami waves would have been hurled across the oceans and debris from the impact site would have shot up with such force that some escaped the atmosphere. As the jettisoned rocks returned they would have burnt up, raining fire across the ground. Plants and animals in the surrounding area would have died instantly or within a matter of days.

Later, as fragments of ash, sulphur and soot from burning forests clogged the air, the world


The asteroid struck in a shallow sea off the coast of Mexico

How peak ring craters form



1 Impact Acoustic waves shatter the rocks, the structure fails and they start to behave like water. Material flows out sideways, spewing up from the edges of the crater

2 Uplift The shattered rocks flow like a water droplet hitting a puddle. The edges of the crater collapse, spilling back towards the centre and shooting up in a jet

3 Collapse So much rock spills into the central jet that it becomes unstable, collapsing again to form a ring of peaks that settle inside the basin of the crater

DID YOU KNOW? *Dinosaurs first appeared following the Permian-Triassic extinction about 248 million years ago*

An extinction in numbers

10km

THE SIZE OF THE ASTEROID

180km

THE WIDTH OF THE CHICXULUB CRATER

65-66 million

THE NUMBER OF YEARS THAT HAVE PASSED SINCE THE IMPACT

11

THE MAGNITUDE OF THE EARTHQUAKE THAT WOULD HAVE SHAKEN EARTH AFTER THE IMPACT

BIGGEST RECORDED QUAKES COMPARED

9.5 VALDIVIA, CHILE, 1990
9.2 PRINCE WILLIAM SOUND, ALASKA, 1964
9.1 SUMATRA, INDONESIA, 2004
9.1 SENDAI, JAPAN, 2011
9.0 KAMCHATKA, RUSSIA, 1952

70%

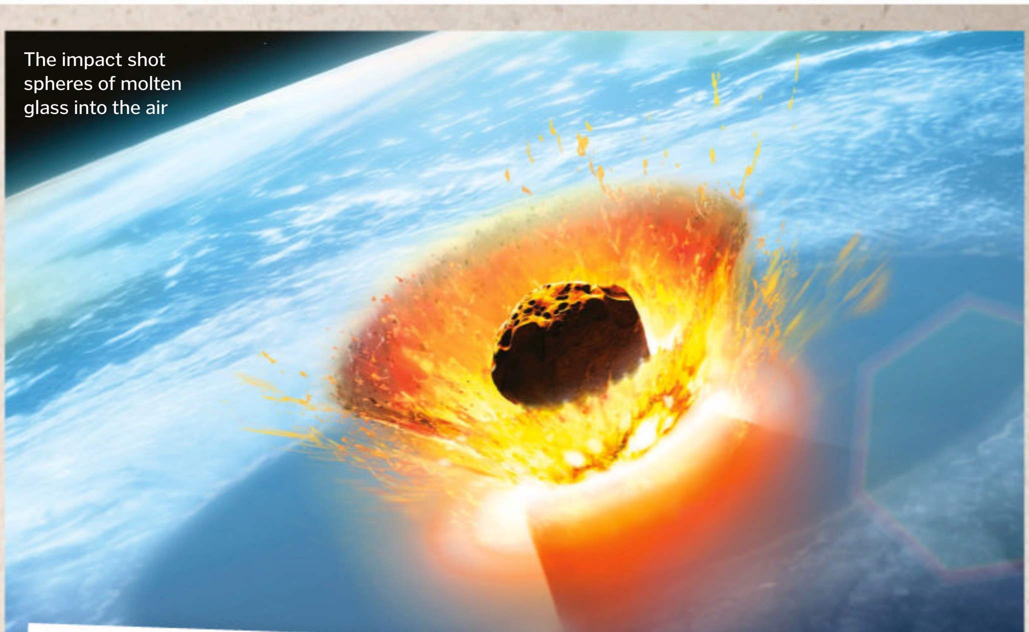
THE ESTIMATED PROPORTION OF SPECIES WIPED OUT BY THE IMPACT

10 degrees

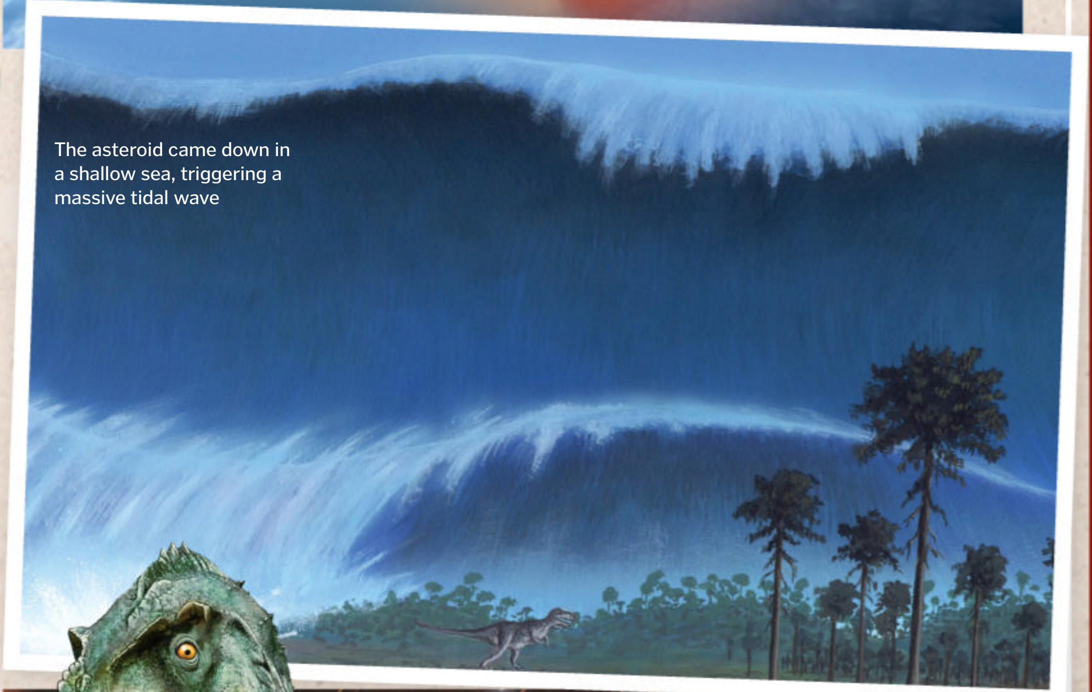
THE RISE IN GLOBAL TEMPERATURE FOLLOWING THE IMPACT

100 million megatons

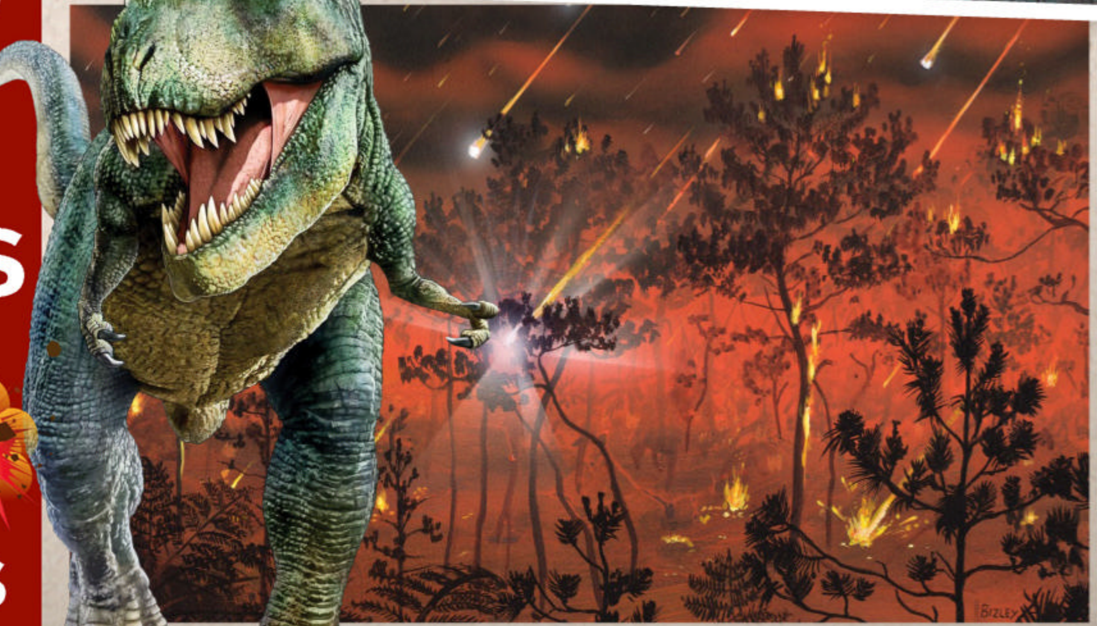
THE BLAST FORCE OF THE IMPACT



The impact shot spheres of molten glass into the air



The asteroid came down in a shallow sea, triggering a massive tidal wave

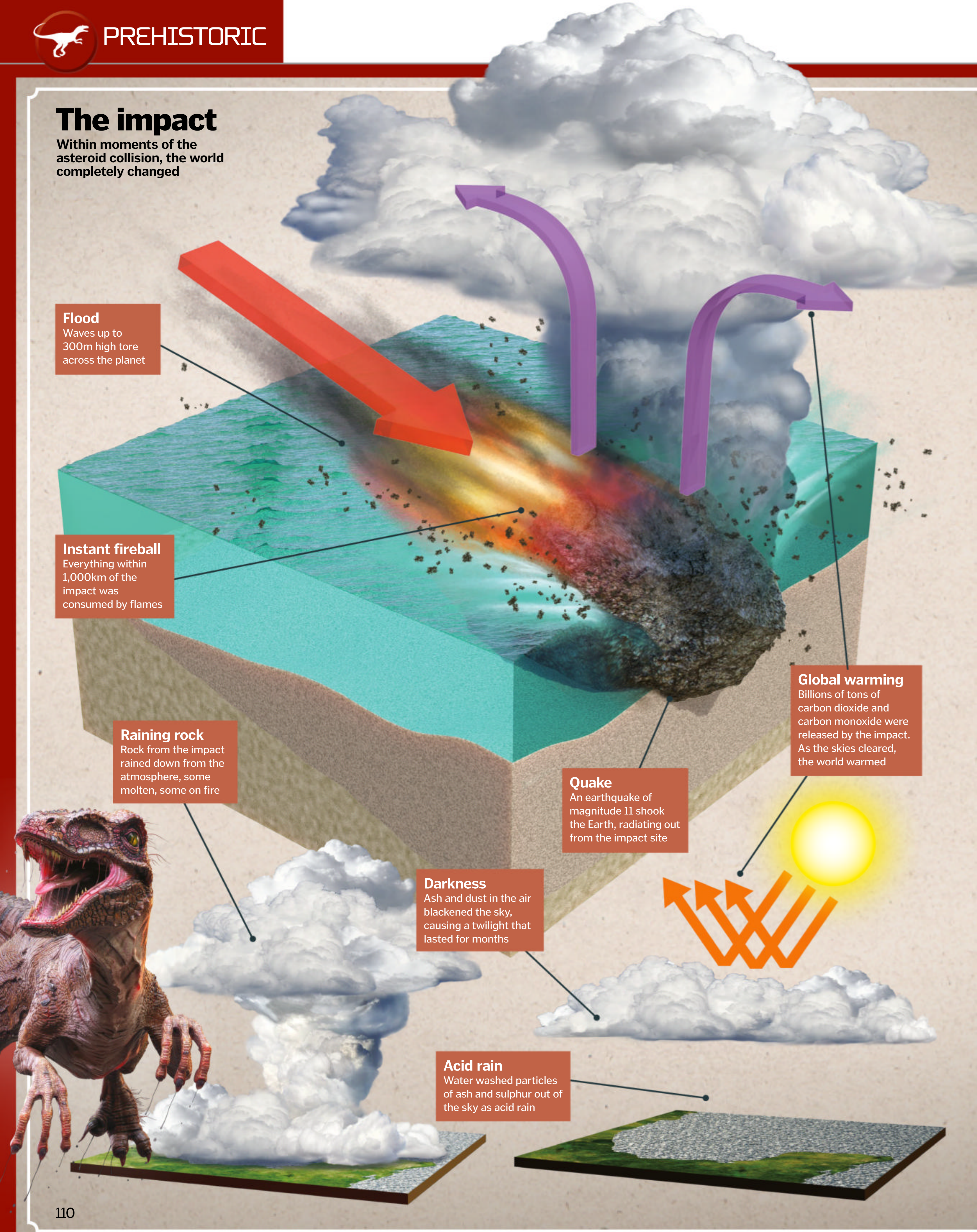


Glass and rock rained from the sky over North America

© SPL; Pixabay; Getty

The impact

Within moments of the asteroid collision, the world completely changed



Flood

Waves up to 300m high tore across the planet

Instant fireball

Everything within 1,000km of the impact was consumed by flames

Raining rock

Rock from the impact rained down from the atmosphere, some molten, some on fire

Quake

An earthquake of magnitude 11 shook the Earth, radiating out from the impact site

Global warming

Billions of tons of carbon dioxide and carbon monoxide were released by the impact. As the skies cleared, the world warmed

Darkness

Ash and dust in the air blackened the sky, causing a twilight that lasted for months

Acid rain

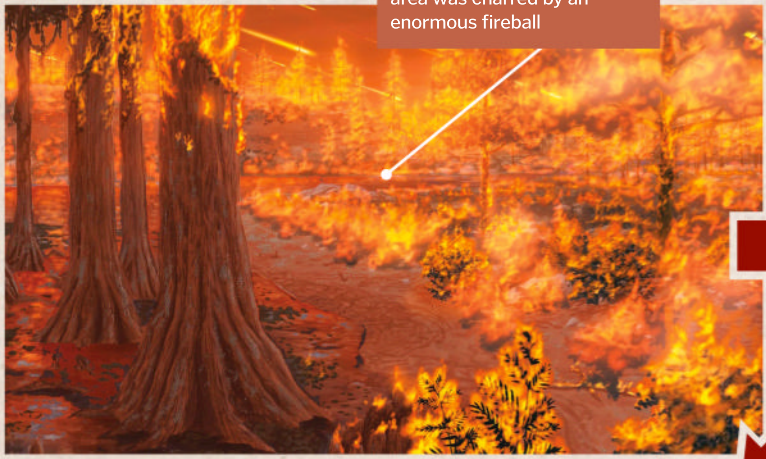
Water washed particles of ash and sulphur out of the sky as acid rain would have been plunged into perpetual twilight for weeks or even months. This 'impact winter' would have hit photosynthesisers hard, knocking out plankton in the seas and plants on land. With the bottom falling out of the food chain, entire ecosystems would have started to feel the strain.

The dust poured out of the sky as acid rain, but the ordeal was not yet over. The Chicxulub crater, as it is now known, sits right in the middle of a three-kilometre-thick layer of carbonate rock. It acts as solid storage for greenhouse gases like carbon dioxide, and when struck, it could have sent temperatures spiralling. As the air finally cleared, billions of tons of these greenhouse gases would have triggered rampant global warming.

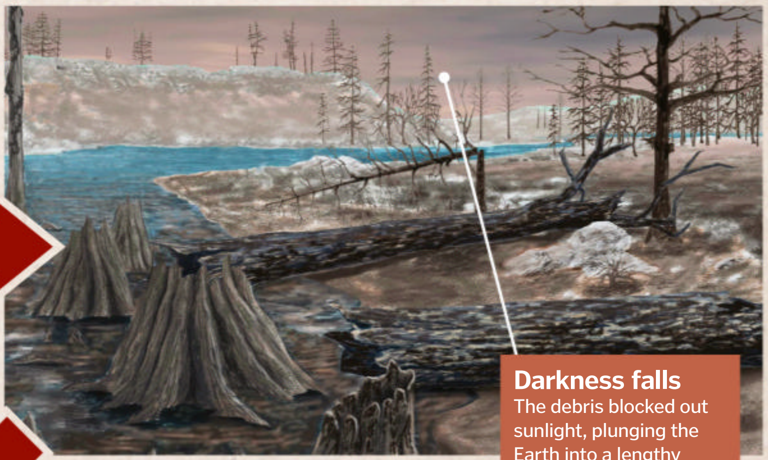
As Hildebrand said at the time of the discovery: "The Chicxulub impact, having presumably produced the largest impact crater on Earth, would have caused a mass extinction."

But even with the crater identified, some people still have their doubts. The most complete fossil record comes from North America, but even so, it's hard to create an exact timeline. Rock that old can't be carbon-dated, so it's not easy to tell if the dinosaurs all died at once, or if the extinction happened gradually. And not all species were preserved, so it's hard to piece together the ecosystem in enough detail to understand what caused it to fall apart. Specific conditions are needed to preserve the bones of fallen animals, and many perished without a trace.

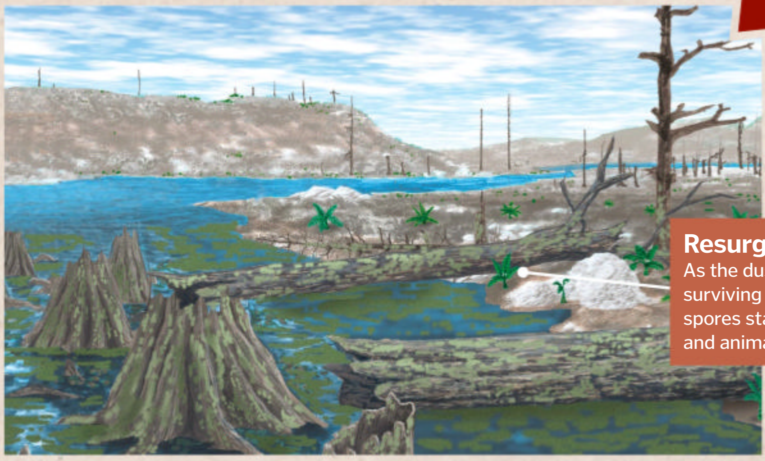
Although there is good evidence that an asteroid did strike at Chicxulub, whether it killed the dinosaurs is hard to confirm. Some scientists argue that the impact happened about 300,000 years before the mass extinction, because some of the fossil evidence sits in layers of sediment above the impact line. It's possible that this chunk of sediment was thrown on top of the rocks by tsunamis triggered by the asteroid, but it's also possible that the sediment was laid



Incineration
Everything in the surrounding area was charred by an enormous fireball



Darkness falls
The debris blocked out sunlight, plunging the Earth into a lengthy period of darkness



Resurgence
As the dust cleared, surviving seeds and spores started to grow and animals emerged

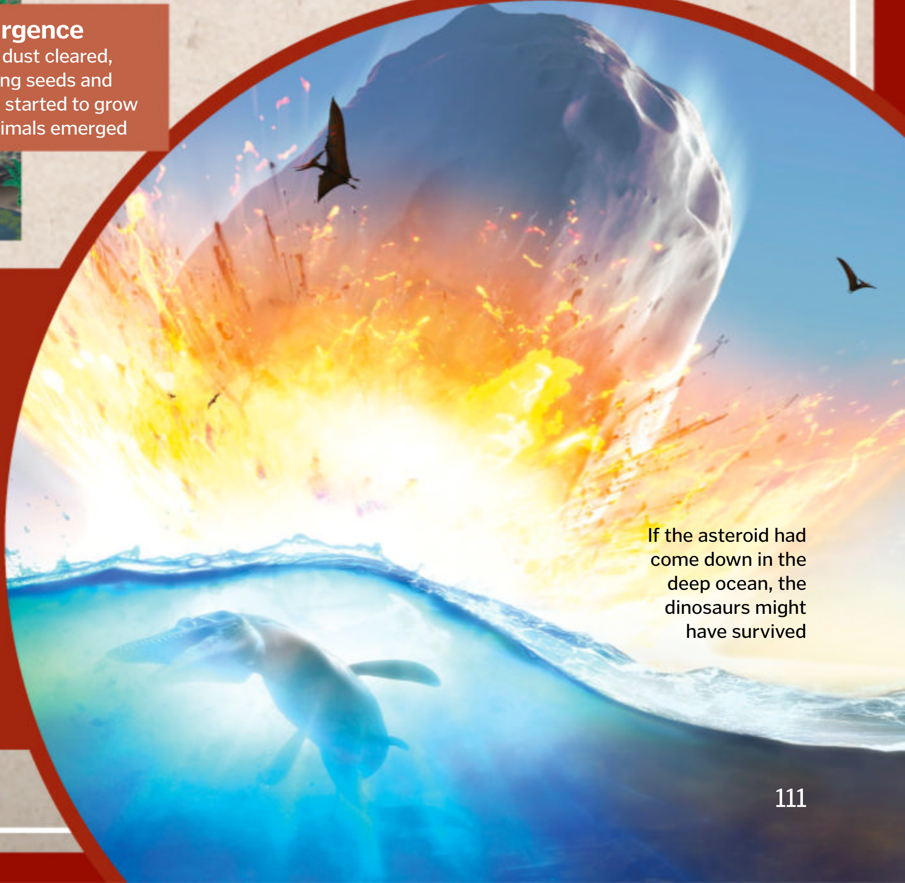
© SPL; Alamy; Illustration by The Art Agency/Barry Croucher

> *"With smoke from burning forests filling the air, the world was plunged into twilight"*

What a difference a moment makes

The Chicxulub crater sits just off the coast of Mexico, in a shallow sea where the sediment was once filled with carbon and sulphur. When the asteroid struck, this rock shot into the atmosphere. 100 billion tons of sulphate particles and carbon – in the form of carbon dioxide, carbon monoxide and methane – entered the air. The sulphate first reflected the light, cooling the planet, but when it washed out of the sky as acid rain the carbon turned the atmosphere into a greenhouse and global temperatures climbed by degrees.

But a BBC documentary recently revealed that if the impact had come just seconds later, the rock would likely have settled in the depths of the ocean. Tsunami waves would still have flooded the surface, but the killer sulphur and greenhouse gases might never have entered the atmosphere and the dinosaurs may have been spared.



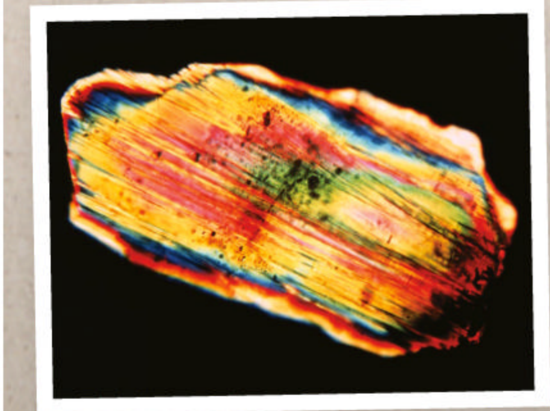
If the asteroid had come down in the deep ocean, the dinosaurs might have survived down gradually and that the extinction of the dinosaurs wasn't as rapid as it might first appear. There's evidence that animals burrowed into the soft rock and there's erosion that looks like it was created by flowing water.

To dig deeper into the role of Chicxulub in the last days of the dinosaurs, scientists have been drilling into the remains of the impact site. Chicxulub is the largest impact crater on Earth. The asteroid that caused this hole was so big that it created a distinctive ring of molten and fragmented rock inside the outline of the crater – the so-called 'peak ring'. Since the impact the crater has been buried in 17 metres of water and 500 metres of limestone.

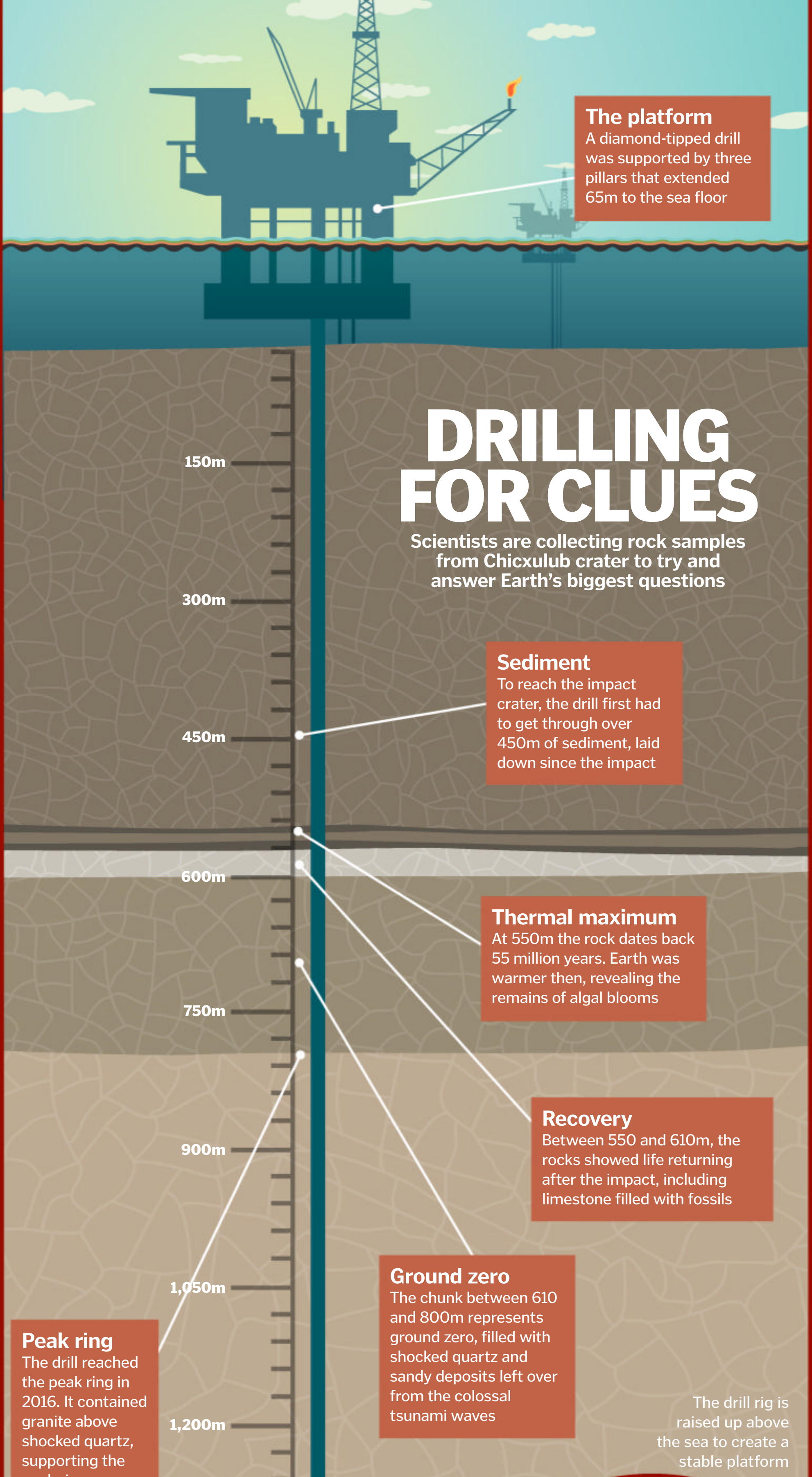
Between 2001 and 2002, the International Continental Drilling Program piled into the structure from the land in Mexico, revealing rock known as 'impact melt' that was likely made from fragments of rock that were shattered, spewed and then glued together when the crater formed. The drills also revealed evidence of hydrothermal activity caused by the huge impact, hinting that steam might have vented onto the crater for more than a million years after the asteroid struck.

In 2016, using a diamond-tipped drill, scientists bored into the structure again, this time targeting the peak ring to find out how it was formed and what happened in the aftermath. One startling discovery was the presence of pink granite in their drill samples. This crustal rock should have been down at a depth of 7,600 metres, but it turned up at 760 metres, evidence of the intense shock that crumpled and shook the Earth below.

There are still many unanswered questions about the extinction of the dinosaurs, and the reality is that we won't ever know the truth of what happened for sure. The Chicxulub crater is thought to have spawned one of the most devastating extinction events of all time, but evidence being gathered from the remains of the crater hint that impacts can nurture life as well as destroy it.



The stress lines inside shocked quartz are caused by intense pressure



DRILLING FOR CLUES

Scientists are collecting rock samples from Chicxulub crater to try and answer Earth's biggest questions

The platform
A diamond-tipped drill was supported by three pillars that extended 65m to the sea floor

Sediment
To reach the impact crater, the drill first had to get through over 450m of sediment, laid down since the impact

Thermal maximum
At 550m the rock dates back 55 million years. Earth was warmer then, revealing the remains of algal blooms

Recovery
Between 550 and 610m, the rocks showed life returning after the impact, including limestone filled with fossils

Ground zero
The chunk between 610 and 800m represents ground zero, filled with shocked quartz and sandy deposits left over from the colossal tsunami waves

Peak ring
The drill reached the peak ring in 2016. It contained granite above shocked quartz, supporting the peak ring formation theory

The drill rig is raised up above the sea to create a stable platform

DID YOU KNOW? *In 1824 William Buckland became the first person to describe a dinosaur when he named the megalosaurus*

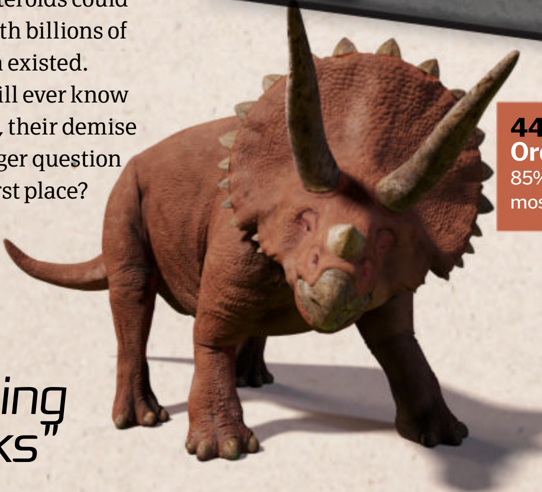
Not only did the KT extinction make way for the rise of mammals; the most recent drilling expedition revealed a large network of channels that were filled with warm water after the impact. At first they would have been too hot for even the hardiest of life forms, but as they cooled, microscopic life could have thrived in the warm, damp cracks, nourished by minerals leaching out of the rocks. And this has exciting implications for the origins of all living things.

Though life was already firmly established by the time the Chicxulub asteroid arrived, the crater gives us a glimpse into the kinds of conditions that might have been present on the ancient, lifeless Earth. Charles Darwin thought that life might have begun in a "warm little pond", where minerals mixed with water and organic molecules. Asteroids are stuffed with organic compounds that could have provided the ingredients for the chemistry life to begin, and if they set up warm, wet, mineral-rich niches when they strike the Earth, they could be the parents of Darwin's little ponds.

As we speak, NASA's OSIRIS-REx is hunting the asteroid Bennu (which scientists have suggested could collide with Earth in the 22nd century) in search of clues as to whether asteroids could have helped life to begin on Earth billions of years before the dinosaurs even existed.

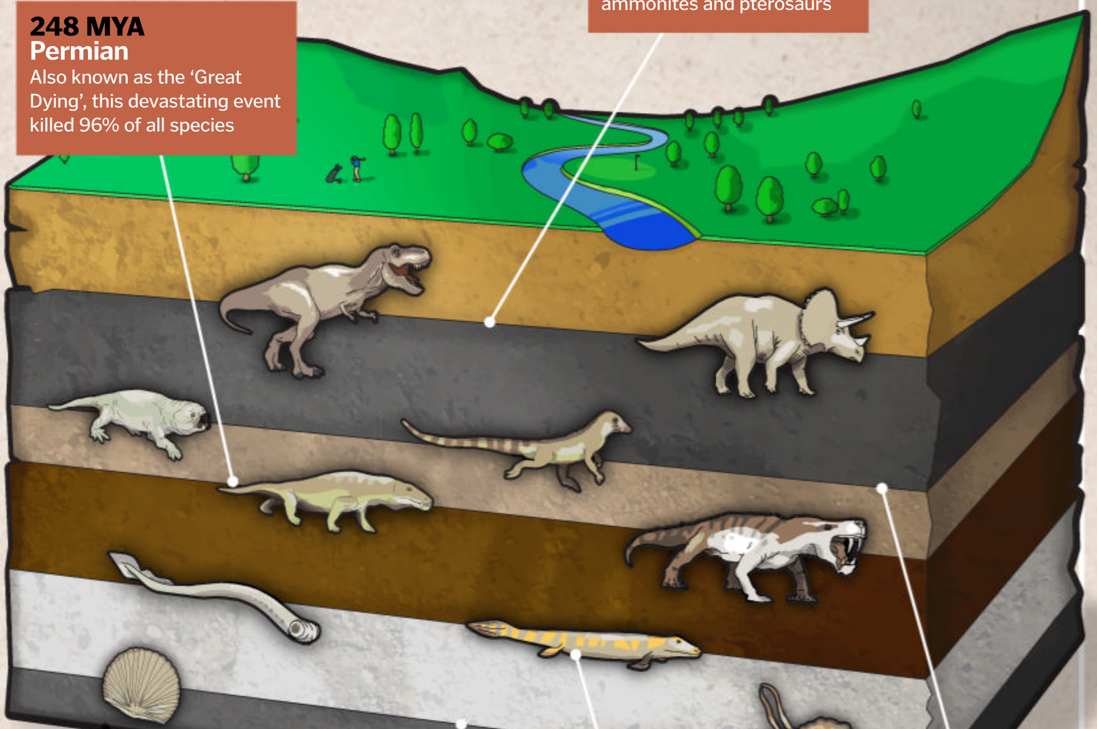
While it is unlikely that we will ever know exactly how the dinosaurs died, their demise might shed light on an even bigger question – how did they get here in the first place?

> "Microbes may have thrived, nourished by minerals leaching out of the rocks"



Mass extinctions

The KT extinction was not the first and it won't be the last



66 MYA
Cretaceous-Tertiary
70% of species were killed, including dinosaurs, ammonites and pterosaurs

248 MYA
Permian
Also known as the 'Great Dying', this devastating event killed 96% of all species

443 MYA
Ordovician-Silurian
85% of life disappeared, most of which was in the sea

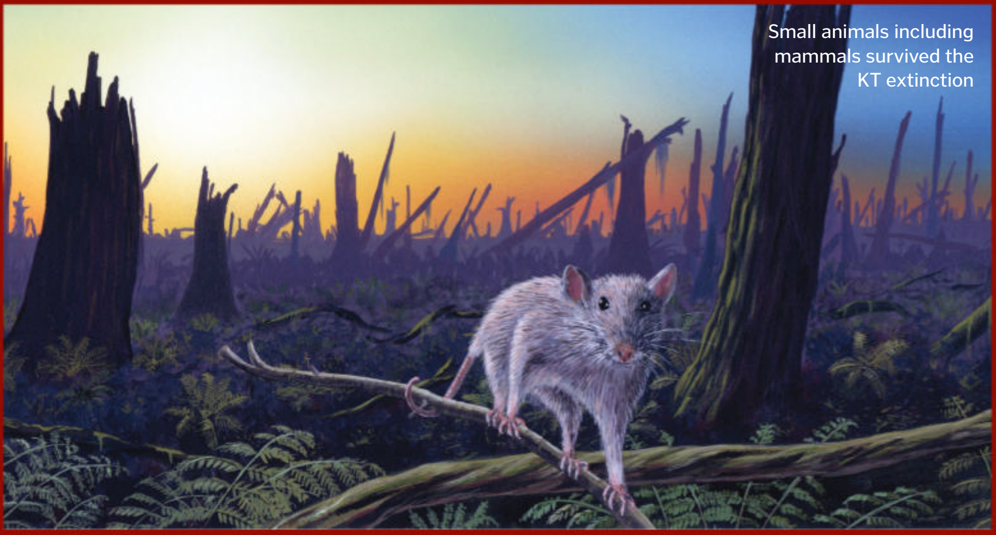
359 MYA
Late Devonian
75% of all species succumbed, including reefs and shallow sea creatures

200 MYA
Triassic-Jurassic
Half of all species expired, including significant numbers of marine animals

Making way for mammals

The KT extinction event devastated the Earth, but without it, we wouldn't be here today. As the dominant land animals struggled to survive in a world charred by debris, blackened by sulphur and soot and heated by greenhouse gases, tiny mammals were shielded in their burrows. Many birds, reptiles and amphibians were also spared; saved by their small body size and flexible, often insect-based, diets. Some freshwater species also fared well; their food chain includes detritus – nutrients released by decomposition – which washes into streams and lakes, providing a steady supply of fuel.

As Earth started to recover there were gaps in the food chain for these animals to fill and the survivors spread out to take the places of the dinosaurs. Over time they evolved to become the huge variety of species that we see today.



Small animals including mammals survived the KT extinction

© USGS; SPL; Illustration by The Art Agency/Nick Sellers

Fossils

Discover life forms that lived millions or billions of years ago before being turned to stone

Extinction is a fact of life that, sooner or later, spells the end for all species. But dead doesn't mean forgotten. The evidence might have remained hidden for millions or even billions of years but, in the fifth century BCE, Greek philosopher Xenophanes discovered the fossils of sea creatures and recognised what they were.

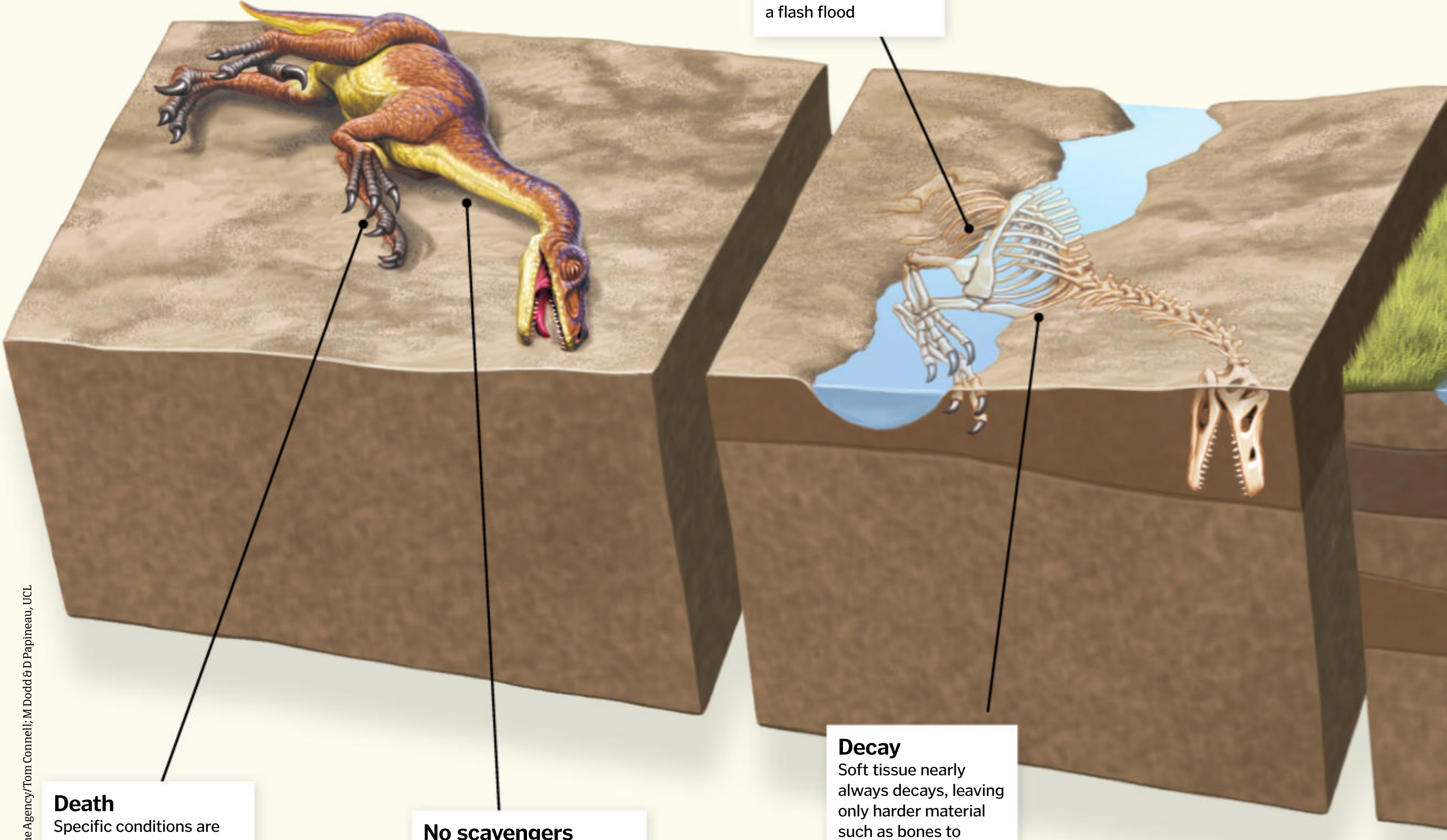
We'll look at exactly how it happens later, but put simply, a fossil was a living organism, which, following its death, turned to stone. And these records can teach us so much. Having found marine fossils on land, for example, Xenophanes was able to say with confidence that the sea once covered what was then dry land. Over the years, fossils have taught us a great deal about Earth's history, and the discoveries continue today.

For example, recent discoveries of fossils dating back to the dawn of our planet, when the Earth was an apparently inhospitable place, have fuelled speculation that life could have started on Mars at about the same time.

Mention fossils and many people think instantly of dinosaurs. These huge lizards might have left some of the largest, most impressive fossils, but they are not nearly the oldest, nor do they have a monopoly on providing a spectacle. The world of fossils is a varied one encompassing wonders as extraordinary as trilobites: large woodlouse-like creatures that crawled on the bed of tropical seas; brightly coloured petrified wood from long lost forests in Arizona; and coprolite – fossilised droppings.

The formation of fossils

How a living organism can be turned into stone and preserved for millions of years



Burial
Protection of the remains is assisted by rapid burial, perhaps by sediment carried by a flash flood

Death
Specific conditions are required for fossil formation to occur; once dead, most organisms decompose completely

No scavengers
For the remains to be fossilised they must not be destroyed by scavengers

Decay
Soft tissue nearly always decays, leaving only harder material such as bones to fossilise, although creatures with exoskeletons can fossilise completely

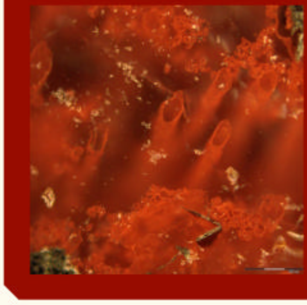
© Alamy; WIKI; Illustration by Art The Agency/Tom Connell; M Dodd & D Papineau, UCL.

DID YOU KNOW? *Small creatures such as insects can be found preserved in amber, the fossilised resin of pine*

Top five fossil discoveries

The oldest fossils

Scientists at UCL have announced the oldest fossils yet. The tube-like structures, found in Canada, are about 3.77 billion years old and grew around deep-sea vents.



The largest fossil

Fossilised bones from Argentina represent the largest known dinosaur. The titanosaur was nearly 40 metres long, stood 20 metres tall, and weighed about 70 tons.

The smallest fossils

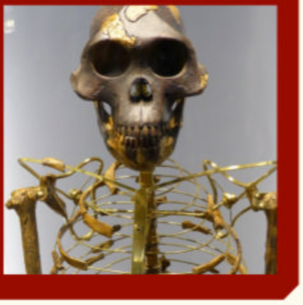
Not all fossils are massive; some are so small you need a microscope to see them. Marine microfossils known as Chitinozoa, for example, can be as little as 0.05mm long.

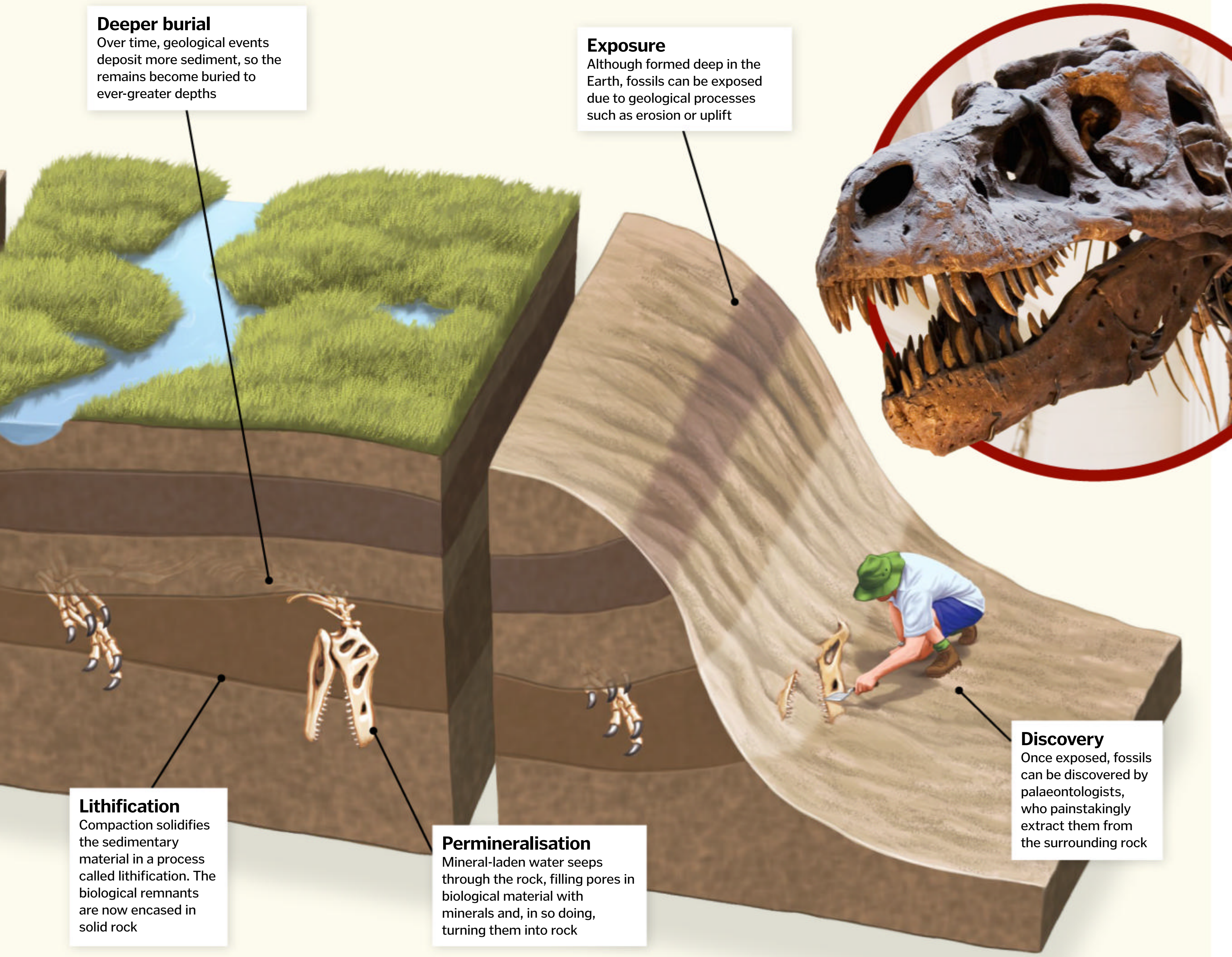
The rarest fossils

Soft tissue usually decays before fossilising, so fossils of creatures with no hard parts are rare. However, researchers at Berlin Free University recently found octopus fossils.

The family tree

Hominin fossils, such as the famous Lucy specimen, have enabled scientists to study human evolution. These findings have helped to shed light on our ancient cousins.





Deeper burial

Over time, geological events deposit more sediment, so the remains become buried to ever-greater depths

Exposure

Although formed deep in the Earth, fossils can be exposed due to geological processes such as erosion or uplift

Lithification

Compaction solidifies the sedimentary material in a process called lithification. The biological remnants are now encased in solid rock

Permineralisation

Mineral-laden water seeps through the rock, filling pores in biological material with minerals and, in so doing, turning them into rock

Discovery

Once exposed, fossils can be discovered by palaeontologists, who painstakingly extract them from the surrounding rock

THE ICE AGE

Uncover the lost world and giant beasts of frozen Earth

For most of Earth's history, the planet has been free of ice, even at the poles. However, for the last 2.4 billion years, Earth has been cycling in and out of freezing ice ages. For millions of years at a time, temperatures plummet and large areas of the globe become trapped under sheets of ice. These glacial periods start gradually. Snow falls during the winter, and fails to melt in the summer, and over time, layer upon layer is built up. The white surface reflects sunlight back into space, and a cycle of cooling begins.

Vast glaciers form at the poles, creeping inwards towards the equator, and Earth's water is locked away into slowly moving ice. As it creeps along, it carves great scars into the landscape beneath. When Earth's water freezes, sea levels drop, revealing land once hidden beneath the oceans. Winds and currents change direction, and even those places untouched by ice undergo significant climate change.

There have been at least five ice ages so far, the first of which transformed the entire planet into a giant snowball. However, within these periods of extreme chill, there have been occasional bursts of warmth. During each ice age, the Earth cycles in and out of glaciation, freezing for tens of thousands of years, thawing temporarily, and then freezing again. As the glaciers warm, water floods back across the land, filling valleys and carving out new tracks in the landscape. Sea levels rise, and winds and currents shift. In fact, we are in the middle of an ice age right now – but we are in a temporary thaw that began around 11,000 years ago. These warm periods are known as 'interglacials' and we don't know exactly how long they last for. Ice sheets still cover Antarctica and Greenland, trapping 75 per cent of Earth's fresh water, and when these finally melt, it will mark the end of the current ice age. Until then, join us as we delve into the history of ice on Earth.

> *"Vast glaciers form at the poles, creeping towards the equator"*

DID YOU KNOW? *Around 52 to 57 million years ago, Earth was so warm that there were trees in the Arctic and Antarctic*

Trigger point

Earth's temperature depends on where it's at in its Milankovitch cycles

The Sun warms our planet, but the amount of heat we receive varies drastically over years, decades and millennia. This is because the Earth's orbit, tilt and axis angle fluctuate in three different patterns, collectively known as the Milankovitch cycles.

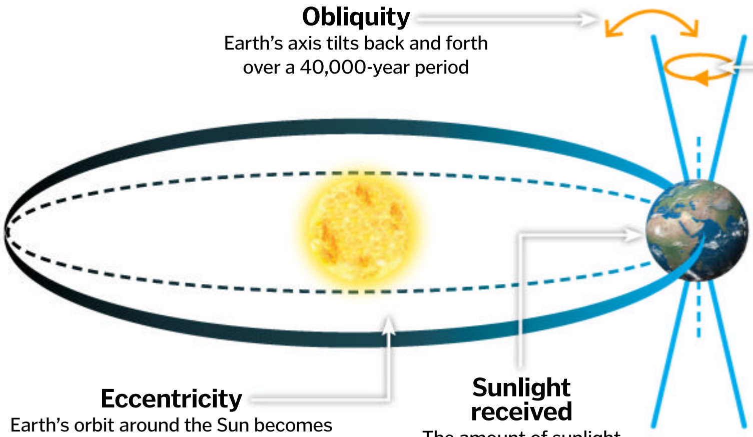
The first cycle is known as eccentricity. Earth moves around the Sun in an elliptical orbit, coming in close and then moving further away again. However, the shape of this orbit changes over time, becoming more elongated (or 'eccentric') and rounder in a cycle that lasts 100,000 years.

The second cycle, known as obliquity, refers to the tilt of Earth relative to the plane of its orbit, which varies from 22.1 to 24.5 degrees over a 40,000-year period. The bigger the angle of the tilt, the more extreme the seasons are on our planet. Finally, Earth also wobbles slightly as it spins, a little like a spinning top as it slows down. This wobble is known as precession, and it takes 26,000-years to complete one cycle.

The amount of solar energy that reaches Earth depends on where it is in all three Milankovitch cycles. At times when the planet receives the least energy, summer temperatures are coldest, and an ice age may be triggered. But the planet's fate also depends on a number of other factors, including the position of continents, ocean circulation and composition of the atmosphere.

The making of an ice age

Several factors come together to tip the Earth into a big freeze



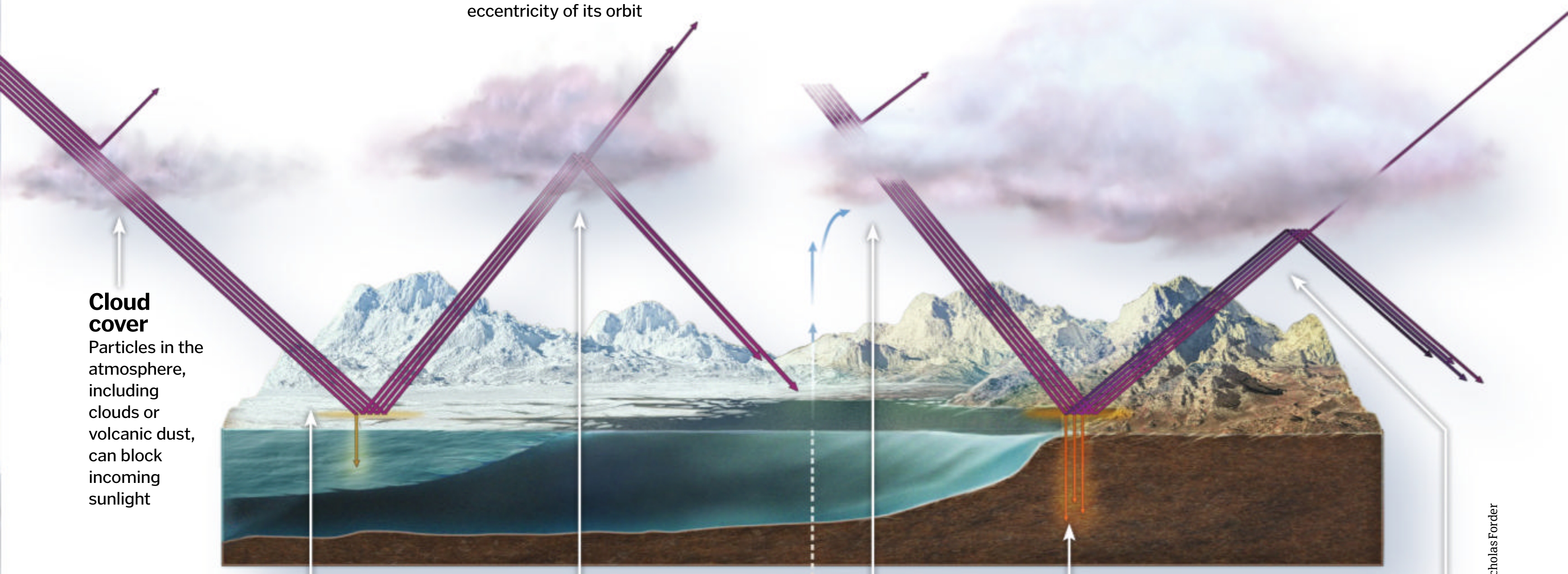
Precession
The Earth wobbles as it spins, completing a full wobble every 26,000 years

Obliquity
Earth's axis tilts back and forth over a 40,000-year period

Eccentricity
Earth's orbit around the Sun becomes more circular and then more elongated on a 100,000-year cycle

Sunlight received
The amount of sunlight that the Earth receives depends on the tilt of its axis, the time of year, and the eccentricity of its orbit

When Earth's water freezes, sea levels drop, and the land beneath is revealed



Cloud cover
Particles in the atmosphere, including clouds or volcanic dust, can block incoming sunlight

Perpetual cooling
Ice reflects 80 per cent of the sunlight that hits it, keeping temperatures low

Reflection
Beneath the clouds, sunlight can be reflected back down towards the Earth, keeping some of the heat in

Melting ice
If ice starts to melt, the amount of reflected light decreases, and cloud cover increases

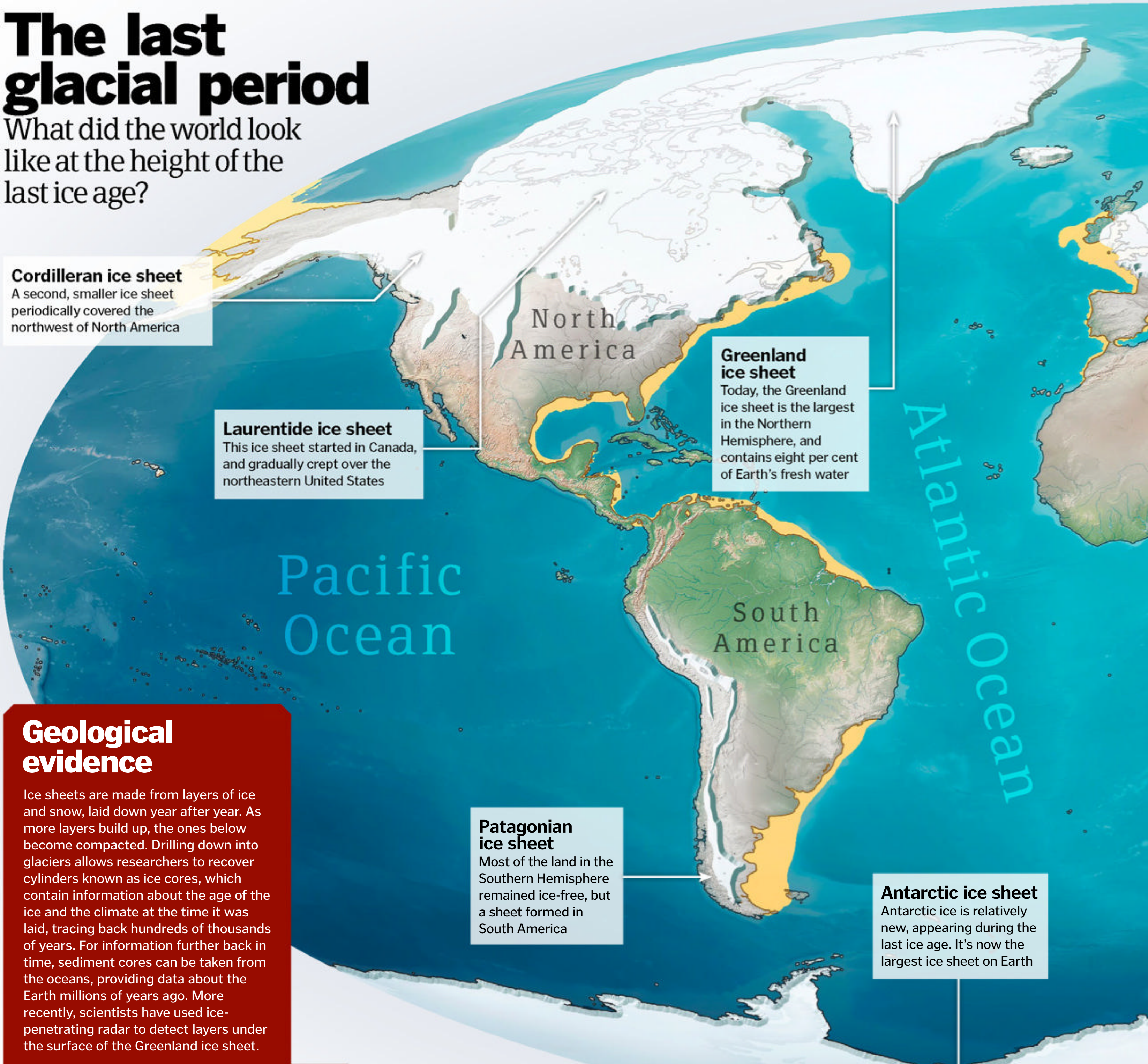
Bare ground
Bare ground absorbs sunlight, contributing to warming

Greenhouse effect
Carbon dioxide is a greenhouse gas that makes the atmosphere warmer. It is trapped in ice, but when this melts, it is released

© Alamy; Illustration by Nicholas Forder

The last glacial period

What did the world look like at the height of the last ice age?



Cordilleran ice sheet
A second, smaller ice sheet periodically covered the northwest of North America

Laurentide ice sheet
This ice sheet started in Canada, and gradually crept over the northeastern United States

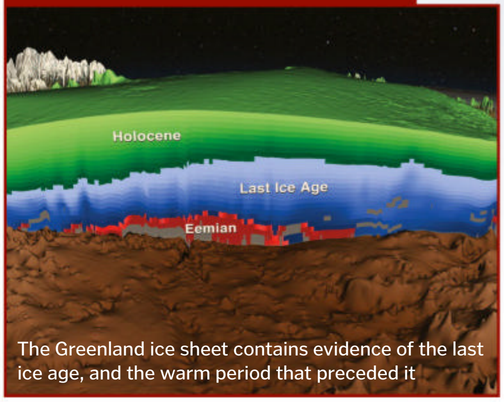
Greenland ice sheet
Today, the Greenland ice sheet is the largest in the Northern Hemisphere, and contains eight per cent of Earth's fresh water

Patagonian ice sheet
Most of the land in the Southern Hemisphere remained ice-free, but a sheet formed in South America

Antarctic ice sheet
Antarctic ice is relatively new, appearing during the last ice age. It's now the largest ice sheet on Earth

Geological evidence

Ice sheets are made from layers of ice and snow, laid down year after year. As more layers build up, the ones below become compacted. Drilling down into glaciers allows researchers to recover cylinders known as ice cores, which contain information about the age of the ice and the climate at the time it was laid, tracing back hundreds of thousands of years. For information further back in time, sediment cores can be taken from the oceans, providing data about the Earth millions of years ago. More recently, scientists have used ice-penetrating radar to detect layers under the surface of the Greenland ice sheet.



The Greenland ice sheet contains evidence of the last ice age, and the warm period that preceded it

Earth's ice through the ages

Our landscape has changed dramatically over the last 2.4 billion years

3 BILLION YRS AGO
1
2 BILLION YRS AGO

2.4-2.1 BILLION YRS AGO

1 Snowball Earth

Our entire planet froze over during the first ever ice age, called the Huronian.

850-630 MILLION YRS AGO

2 Slushball Earth

During the Cryogenian ice age, a band of liquid ocean remained at the equator.

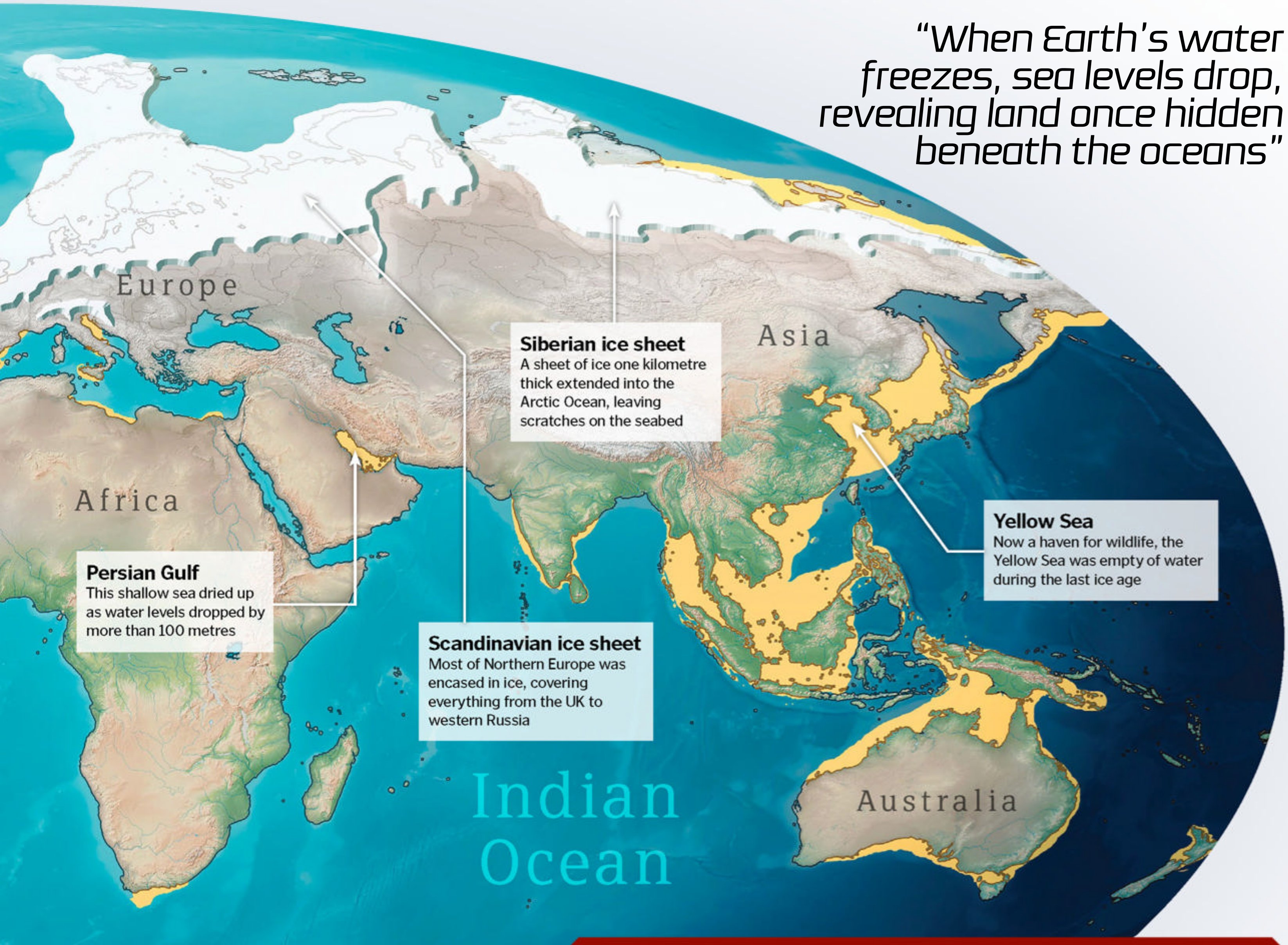
460-430 MILLION YRS AGO

3 Mass extinction

The Andean-Saharan ice age accompanied the second largest mass extinction in history.

DID YOU KNOW? *Ten per cent of the Earth's surface is covered in glaciers, holding 75 per cent of the planet's fresh water*

> "When Earth's water freezes, sea levels drop, revealing land once hidden beneath the oceans"



Siberian ice sheet
A sheet of ice one kilometre thick extended into the Arctic Ocean, leaving scratches on the seabed

Yellow Sea
Now a haven for wildlife, the Yellow Sea was empty of water during the last ice age

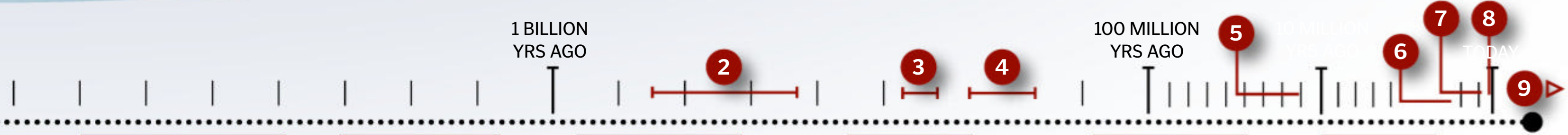
Persian Gulf
This shallow sea dried up as water levels dropped by more than 100 metres

Scandinavian ice sheet
Most of Northern Europe was encased in ice, covering everything from the UK to western Russia

Land bridges

When Earth's water freezes into glaciers, sea levels drop, exposing land once hidden beneath the waves. These 'land bridges' connect islands and continents, allowing animals to move from one place to another. The most well-known is the Bering Land Bridge, which once linked Siberia to Alaska, closing the gap between Asia and North America. This bridge provided a sheltered path that took early humans to the Americas. In the past, solid ground has also appeared between the UK and Europe, connecting the islands of the Indonesian archipelago, and linking Australia to New Guinea.

Today, the Bering Strait is flooded with water



360-260 MILLION YRS AGO

4 The arrival of plants

Plants sucked carbon dioxide from the air, causing the Karoo ice age.

20 MILLION YRS AGO

5 The making of Antarctica

The beginnings of the Antarctic ice sheet started to form.

2.5 MILLION YRS AGO

6 Quaternary ice age

The latest cold snap started very recently, and is still going on to this day.

11,000 YRS AGO

7 Interglacial period

We are in the middle of a short intermission in the current ice age.

1300-1800 YRS AGO

8 Little Ice Age

In recent history, Earth experienced a sharp drop in temperature.

THE FUTURE...

9 Next ice age

Human activity is warming the planet, and the date of the next ice age is uncertain.

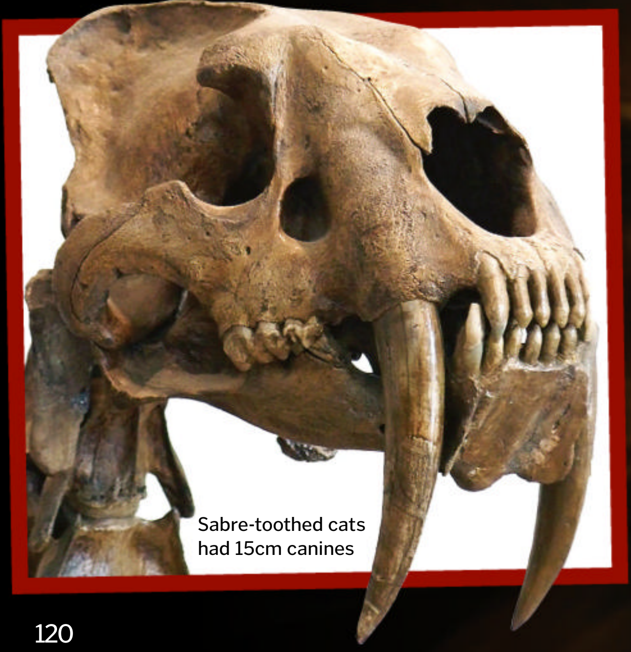
The hardened survivors

Meet the giant beasts that conquered the frozen wilderness

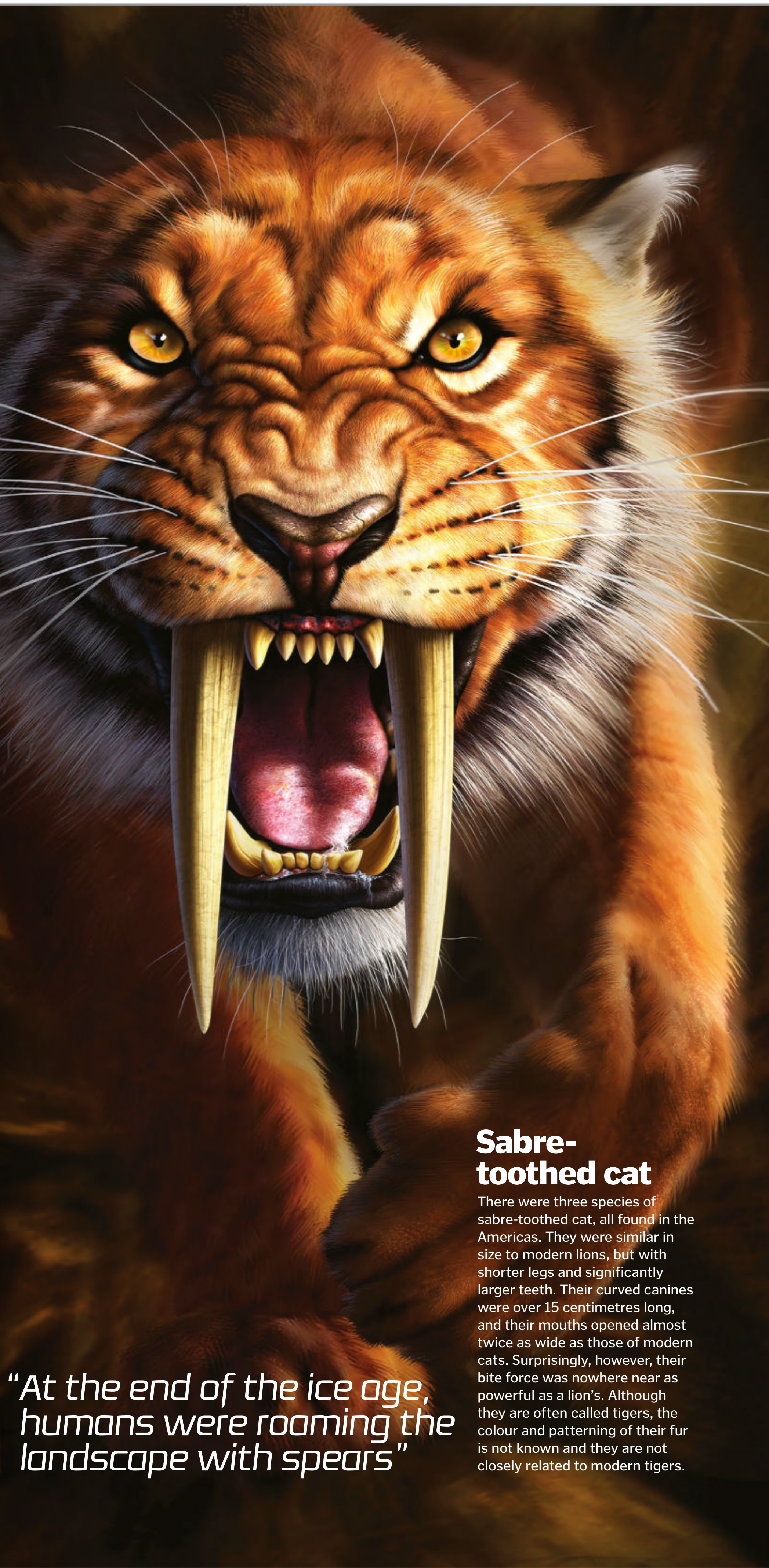
Before the end of the last ice age, Earth was inhabited by weird and wonderful mammalian megafauna. Food was abundant, allowing animals to grow to enormous sizes, and the larger they got, the more protection they had from the cold. Not all of the animals that lived during the ice age inhabited the coldest parts of the planet; many, like ground sloths and sabre-toothed cats, preferred to live in warmer and more temperate regions further south.

There were also many true ice survivors, including fur-covered woolly mammoths, musk oxen, and giant dire wolves. Their stocky bodies helped to minimise heat loss through their skin, and layers of fat and hair provided thick insulation. However, when the temperatures started to rise, these animals began to struggle.

During interglacial periods, glaciers melt and sea levels rise; valleys flood and lakes appear in the landscape. Ocean currents change direction, and winds shift. And as if that weren't enough pressure, at the end of this particular ice age, humans were roaming the landscape with spears. Our ancestors competed with top predators, and hunted some of the largest animals. Mammoths and mastodons were 'keystone' species, so large and numerous that their activities carved out vital niches that other animals needed for survival. But around 50,000 years ago, the ice age megafauna started to die out, and by the time the glaciers had retreated, at least 177 large mammal species were extinct.



Sabre-toothed cats had 15cm canines



Sabre-toothed cat

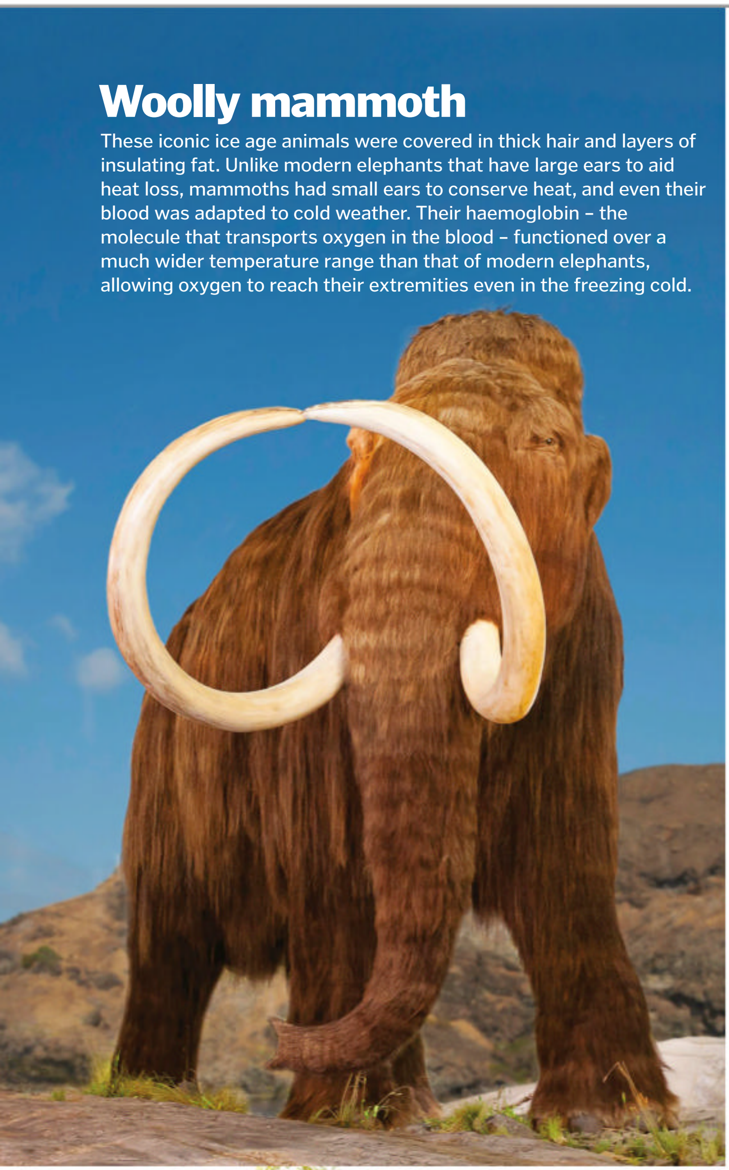
There were three species of sabre-toothed cat, all found in the Americas. They were similar in size to modern lions, but with shorter legs and significantly larger teeth. Their curved canines were over 15 centimetres long, and their mouths opened almost twice as wide as those of modern cats. Surprisingly, however, their bite force was nowhere near as powerful as a lion's. Although they are often called tigers, the colour and patterning of their fur is not known and they are not closely related to modern tigers.

> *"At the end of the ice age, humans were roaming the landscape with spears"*

DID YOU KNOW? *The first fossilised mastodon tooth was found by a farmer in 1705 and weighed 2kg – he traded it for rum!*

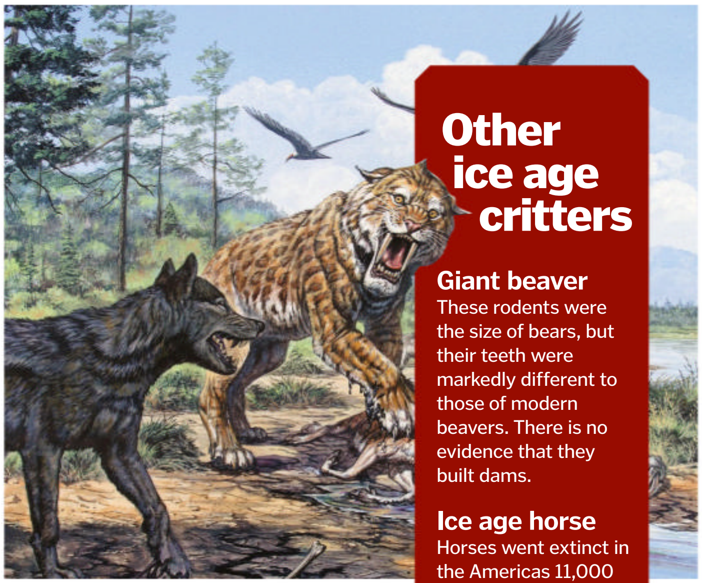
Woolly mammoth

These iconic ice age animals were covered in thick hair and layers of insulating fat. Unlike modern elephants that have large ears to aid heat loss, mammoths had small ears to conserve heat, and even their blood was adapted to cold weather. Their haemoglobin – the molecule that transports oxygen in the blood – functioned over a much wider temperature range than that of modern elephants, allowing oxygen to reach their extremities even in the freezing cold.



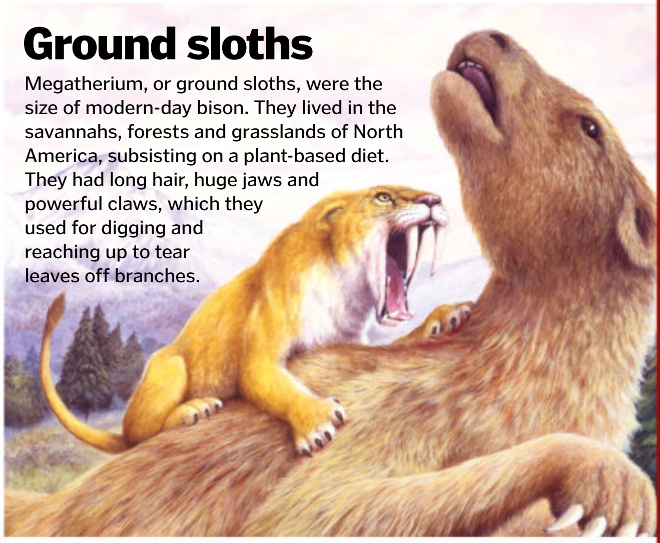
Dire wolf

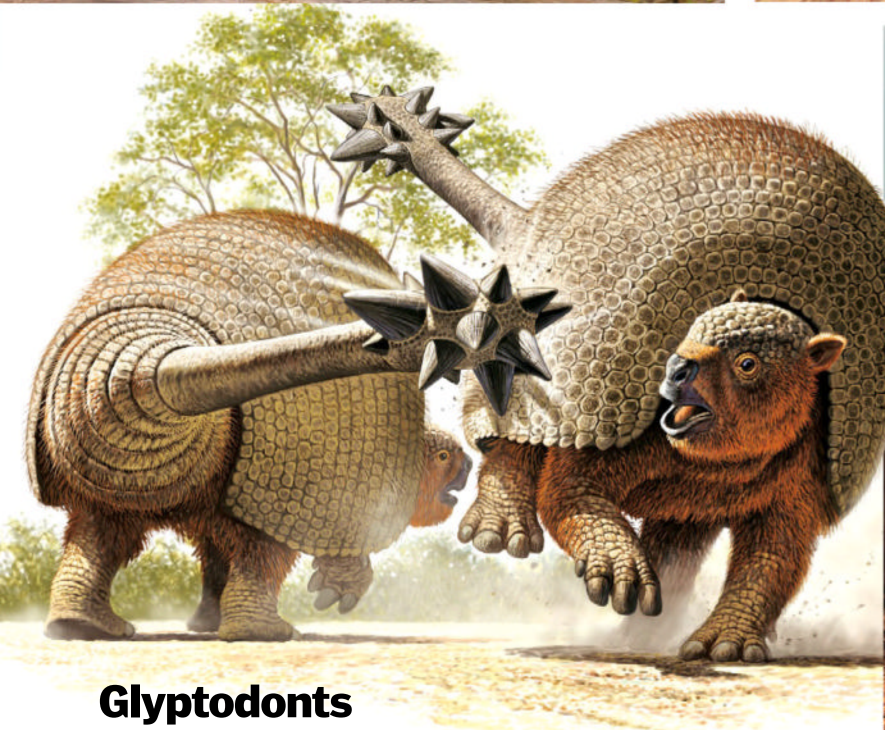
These prehistoric wolves were slightly larger than their modern counterparts, with short legs, broad heads, and smaller brains. While grey wolves use speed and teamwork to wear their prey down, these snow hunters are thought to have preferred ambush tactics. Grey wolves existed alongside these fearsome hunters but 10,000 years ago, dire wolves had disappeared, along with other ice age predators like sabre-toothed cats and American lions.



Ground sloths

Megatherium, or ground sloths, were the size of modern-day bison. They lived in the savannahs, forests and grasslands of North America, subsisting on a plant-based diet. They had long hair, huge jaws and powerful claws, which they used for digging and reaching up to tear leaves off branches.



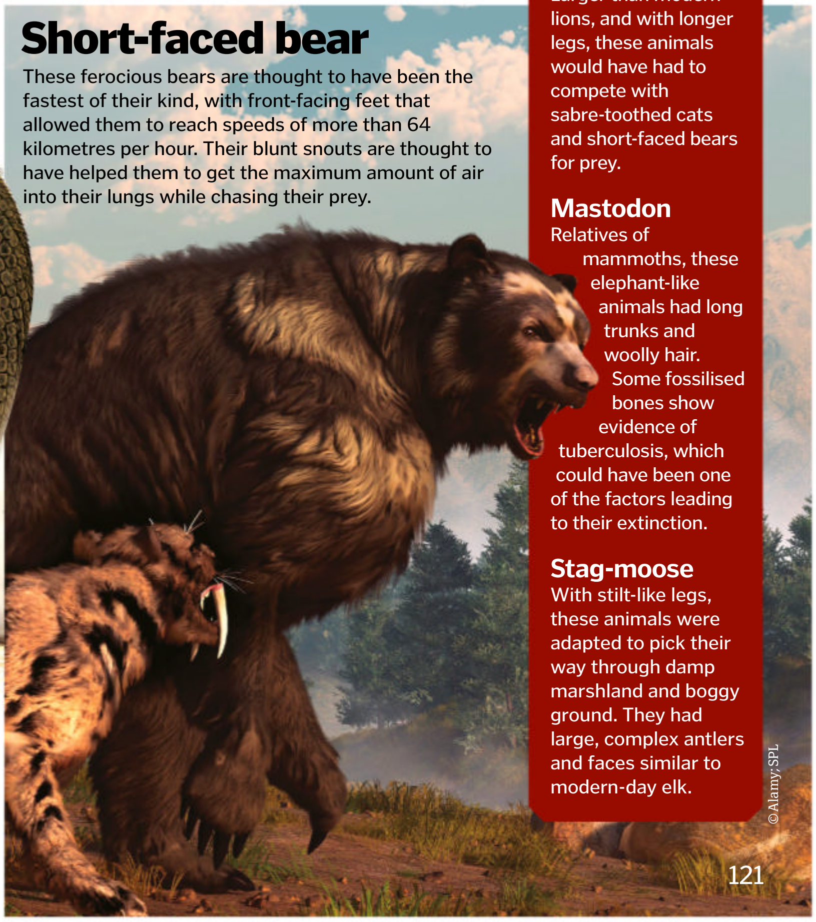


Glyptodonts

These bizarre-looking beasts were the size of a car, and the heaviest weighed more than a ton. Related to modern armadillos, they had a protective exoskeleton made from plates of bone called osteoderms, and a fearsome-looking clubbed tail. While armadillos can flex their armour, glyptodonts had fused bones with rigid shells that turned them into walking tanks.

Short-faced bear

These ferocious bears are thought to have been the fastest of their kind, with front-facing feet that allowed them to reach speeds of more than 64 kilometres per hour. Their blunt snouts are thought to have helped them to get the maximum amount of air into their lungs while chasing their prey.



Other ice age critters

Giant beaver

These rodents were the size of bears, but their teeth were markedly different to those of modern beavers. There is no evidence that they built dams.

Ice age horse

Horses went extinct in the Americas 11,000 years ago, but they managed to survive in Eurasia and Africa. Modern horses in the Americas – as well as donkeys and asses – are the descendents of these survivors.

Musk ox

These heavy-set, woolly animals almost went extinct due to hunting during the last ice age, and the warming climate that followed. There are still some musk oxen in Canada today, but their numbers are vastly reduced.

American lion

Larger than modern lions, and with longer legs, these animals would have had to compete with sabre-toothed cats and short-faced bears for prey.

Mastodon

Relatives of mammoths, these elephant-like animals had long trunks and woolly hair. Some fossilised bones show evidence of tuberculosis, which could have been one of the factors leading to their extinction.

Stag-moose

With stilt-like legs, these animals were adapted to pick their way through damp marshland and boggy ground. They had large, complex antlers and faces similar to modern-day elk.

© Alamy; SPL

Living in a frozen world

How did early humans survive the ice age?

Early humans had begun to explore Europe, Asia and North America by the time the last glacial period set in around 110,000 years ago – this is what is often referred to as *the* Ice Age. Although many humans lived far enough to the south that they escaped the advancing ice, some had to brave fierce drops in temperature. They had three choices: migrate, adapt or die.

Humans weren't alone in their struggle. Another hominid species, Neanderthals, were also attempting to brave the cold. They were stockier than humans, with shorter forearms and shins, which would have helped to conserve body heat. Neanderthals built simple shelters, used animal skins for blankets, and kept themselves warm beside wood-fuelled fires. In mild conditions, they hunted red deer, and as it grew colder, they switched to reindeer. Eventually, when the landscape froze, they moved south in search of warmth.

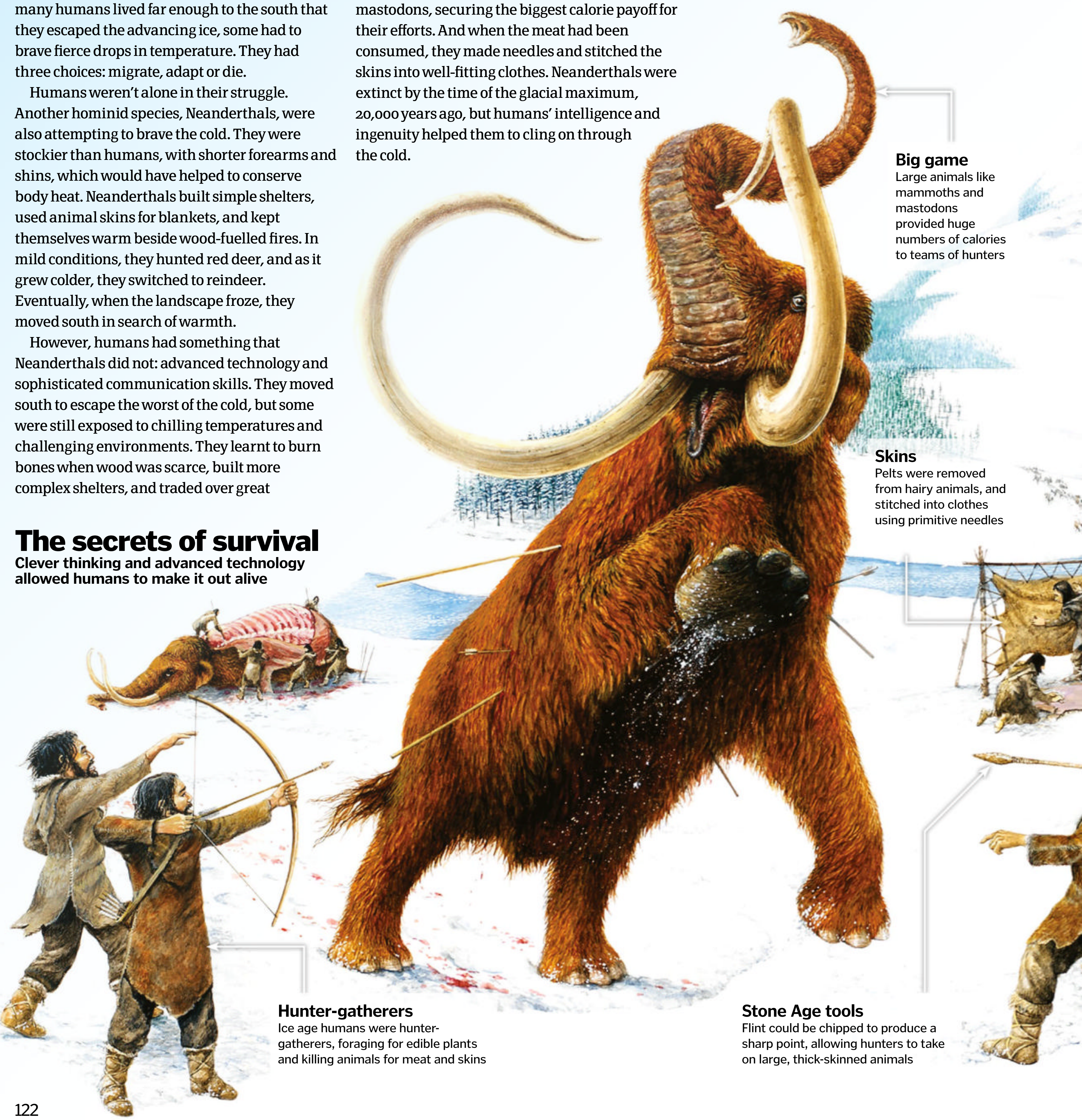
However, humans had something that Neanderthals did not: advanced technology and sophisticated communication skills. They moved south to escape the worst of the cold, but some were still exposed to chilling temperatures and challenging environments. They learnt to burn bones when wood was scarce, built more complex shelters, and traded over great distances, thereby making the most of their social networks.

Humans banded together and used sharp tools to hunt large animals like mammoths and mastodons, securing the biggest calorie payoff for their efforts. And when the meat had been consumed, they made needles and stitched the skins into well-fitting clothes. Neanderthals were extinct by the time of the glacial maximum, 20,000 years ago, but humans' intelligence and ingenuity helped them to cling on through the cold.

> *"Humans moved south to escape the worst of the cold"*

The secrets of survival

Clever thinking and advanced technology allowed humans to make it out alive



Big game
Large animals like mammoths and mastodons provided huge numbers of calories to teams of hunters

Skins
Pelts were removed from hairy animals, and stitched into clothes using primitive needles

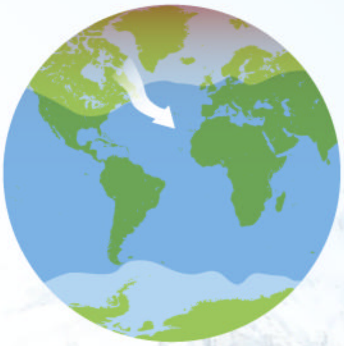
Hunter-gatherers
Ice age humans were hunter-gatherers, foraging for edible plants and killing animals for meat and skins

Stone Age tools
Flint could be chipped to produce a sharp point, allowing hunters to take on large, thick-skinned animals

DID YOU KNOW? *Ice age humans dug into the permafrost to build 'ice cellars', where they stored supplies of food*

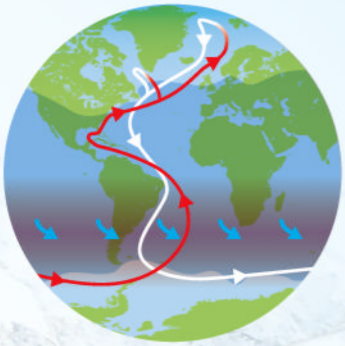
The end of the ice age

What caused frozen Earth to thaw?



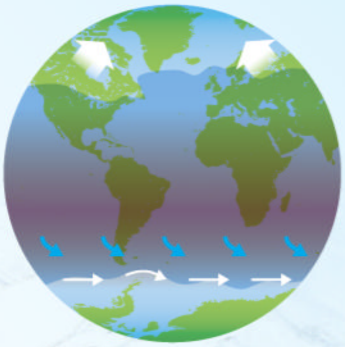
20,000 years ago

Towards the end of the last ice age, Earth tilted on its orbit, pointing the Northern Hemisphere towards the Sun. With more light and more heat striking the frozen surface, ice sheets in this area finally began to melt, and water flooded into the Atlantic Ocean.



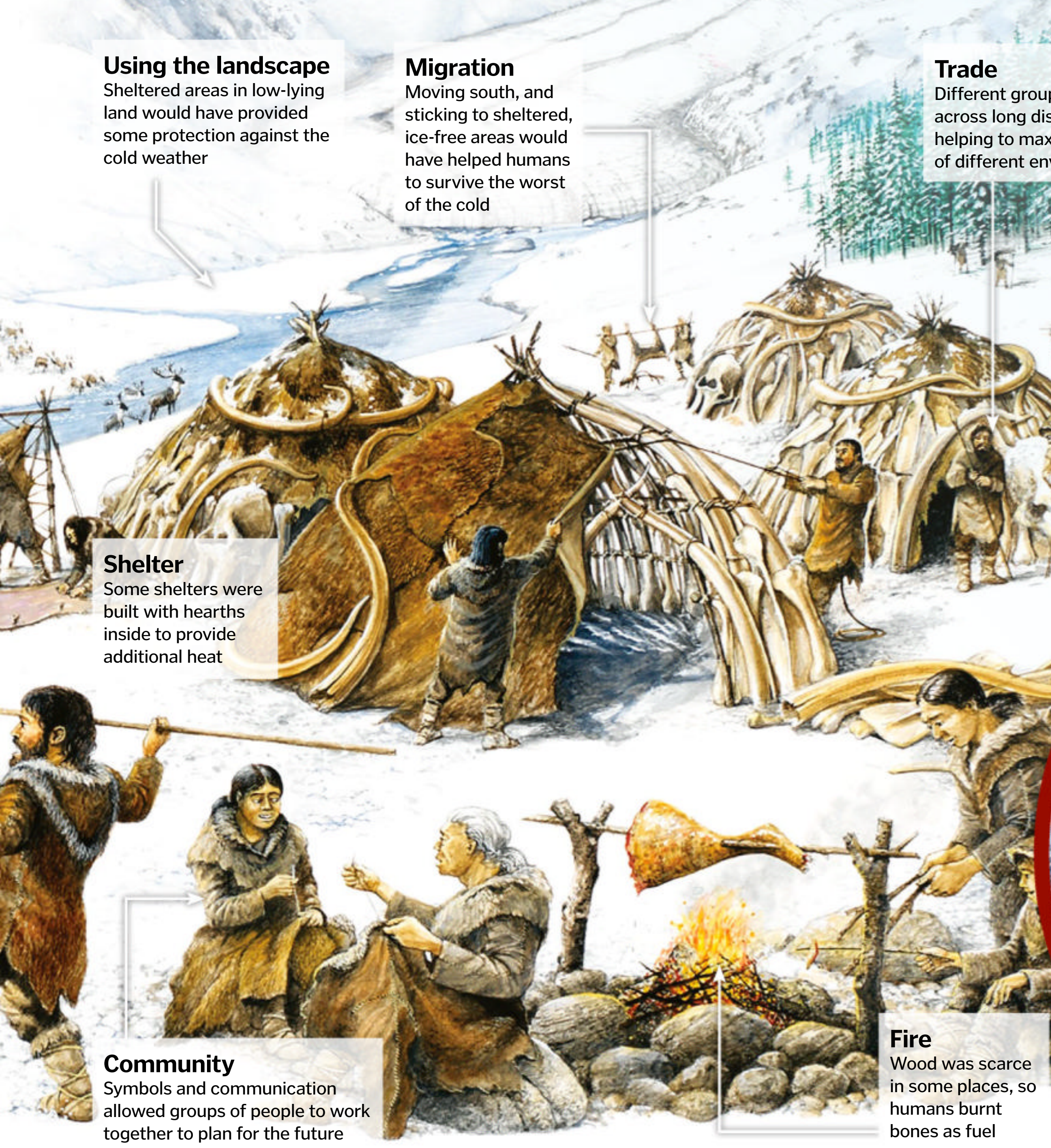
19,000 years ago

The influx of cold water into the Atlantic disrupted the ocean currents, slowing the flow of warm water moving up from the south. With nowhere to go, these hot streams remained in the Southern Hemisphere, warming oceans and melting ice.



17,500 years ago

The flow of ocean currents affects the wind, and with the disruption in the north, winds pushed downwards. As the southern glaciers melted, more water was released into the oceans, and with it came carbon dioxide – a greenhouse gas that helps to trap heat.



Using the landscape
Sheltered areas in low-lying land would have provided some protection against the cold weather

Migration
Moving south, and sticking to sheltered, ice-free areas would have helped humans to survive the worst of the cold

Trade
Different groups traded across long distances, helping to maximise the use of different environments

Shelter
Some shelters were built with hearths inside to provide additional heat

Community
Symbols and communication allowed groups of people to work together to plan for the future

Fire
Wood was scarce in some places, so humans burnt bones as fuel

Is winter coming?

The impact of humans on Earth could affect the forecast

Technically, we are still in the middle of an ice age. The cold period that saw the rise and fall of woolly mammoths has not yet ended. We are in an interglacial period, and if history is anything to go by, these last for around 15,000 to 20,000 years.

11,000 years have already passed, but whether another cold snap is around the corner is a matter of debate. In the late 17th century, there was a Little Ice Age, during which time rivers froze and ice fields refused to melt during the summer. This is thought to have been caused by a period known as the Maunder Minimum.

The Sun's changing magnetic field produces sunspots, which normally increase and decrease in a pattern that repeats every 11 years, but during the Little Ice Age, this cycle all but stopped. For 70 years, there were only around 50 recorded spots, when normally there would have been closer to 50,000.

In 2008, sunspots disappeared again, and when they eventually returned in 2014, they were weaker than at any other time on record. However, since the 17th century, humans have been busy expanding and industrialising, and, at least in part thanks to us, global temperatures are rising. Whether this will have an effect on the ice age cycle remains to be seen.

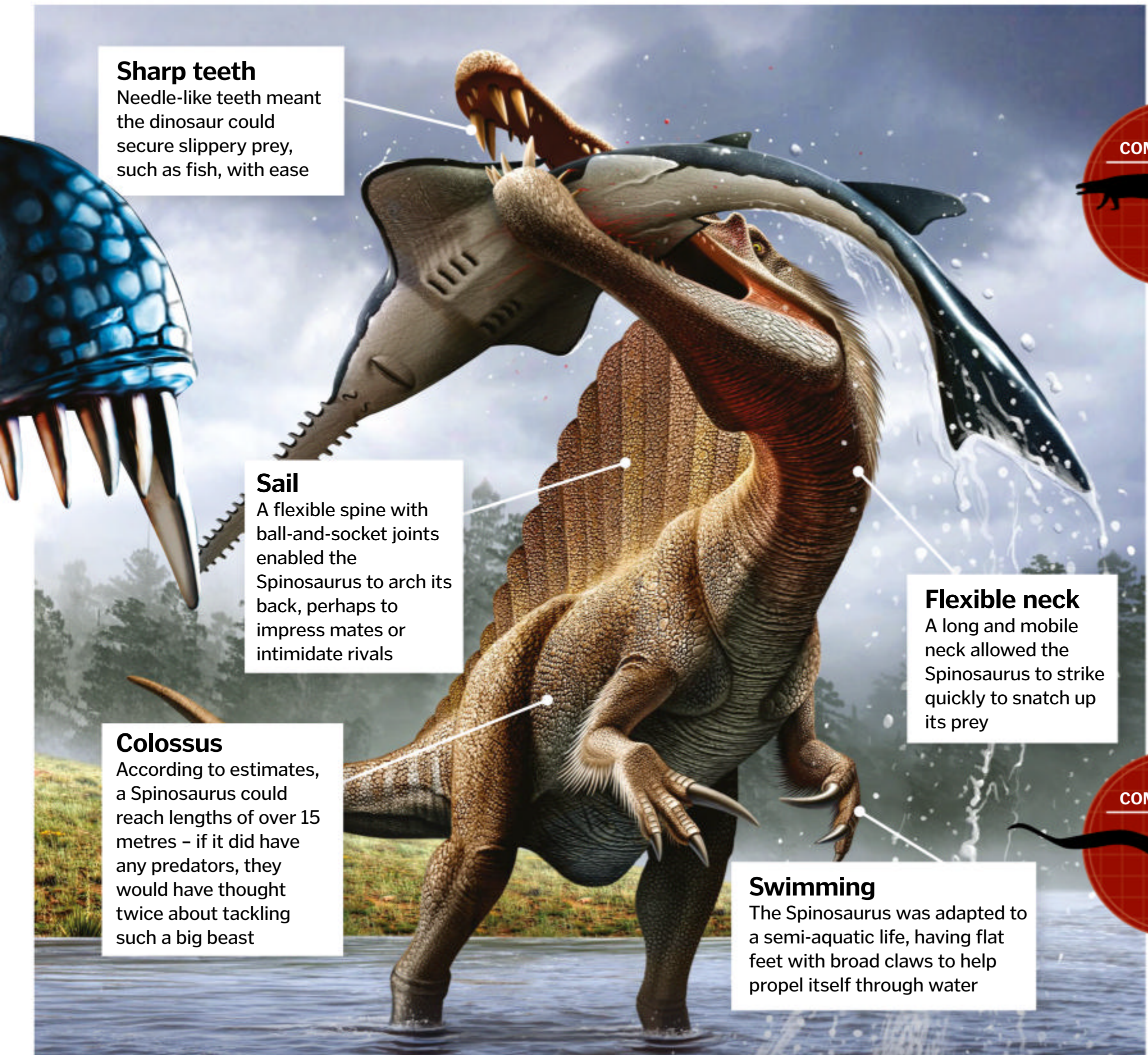
The Little Ice Age is thought to have inspired tales of white Christmases

© Thinkstock; Illustration by Jo Smolaga

Prehistoric monsters

Meet the enormous ancient predators that stalked the land, dominated the oceans and terrorised the skies

DID YOU KNOW? *The Spinosaurus's centre of gravity was pitched forward, so on land it may have travelled on all fours*



Sharp teeth
Needle-like teeth meant the dinosaur could secure slippery prey, such as fish, with ease

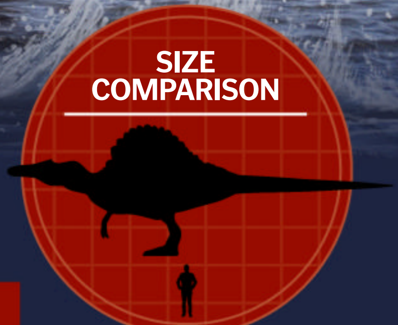
Sail
A flexible spine with ball-and-socket joints enabled the Spinosaurus to arch its back, perhaps to impress mates or intimidate rivals

Flexible neck
A long and mobile neck allowed the Spinosaurus to strike quickly to snatch up its prey

Colossus
According to estimates, a Spinosaurus could reach lengths of over 15 metres – if it did have any predators, they would have thought twice about tackling such a big beast

Swimming
The Spinosaurus was adapted to a semi-aquatic life, having flat feet with broad claws to help propel itself through water

Colossal cretaceous carnivore

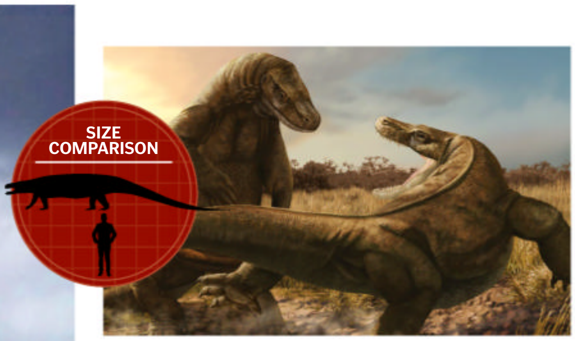


SPINOSAURUS ▶ 112-97 MYA

Move over T rex: the spine lizard was the true king

Nearly three storeys high and longer than a bus, the Spinosaurus was the largest carnivorous dinosaur to walk the Earth. The 'spine lizard' roamed the coastal plains and swamps of North Africa in the mid-Cretaceous period. Unlike the Tyrannosaurus rex, Spinosaurus' teeth were not serrated, so they were not used for tearing through flesh; its conical teeth, powerful jaws and long snout were better suited to snapping up large fish. It's thought that Spinosaurus was the first dinosaur to swim, and that it spent a lot of time in the water where it could snatch aquatic creatures with its razor-sharp claws. There is evidence to suggest Spinosaurus' snout openings and skull cavities were part of a pressure-detection system, so it could sense the movements of fish even in murky waters.

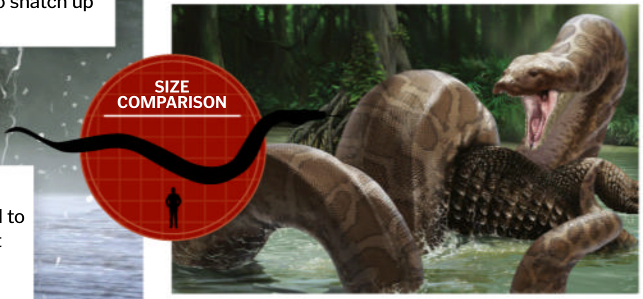
The giant carnivore's defining feature was the 1.5-metre-high 'sail' on its back, formed by tall vertebral spines. This may have been a display to attract mates or intimidate rivals, help regulate temperature, or possibly support a camel-like hump of stored fat that Spinosaurus could build up when food was plentiful.



Mega monitor lizard

VARANUS PRISCUS ▶ 1.8 MYA-40,000 YA

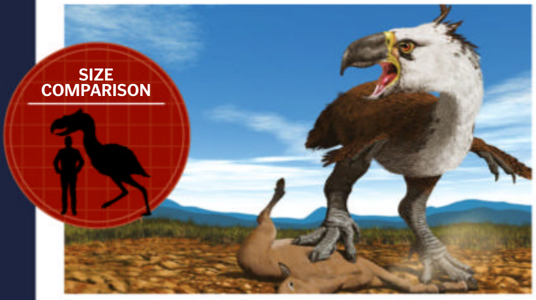
Also known as Megalania, these giant goannas of eastern Australia were the largest land lizards of all time. They could grow to lengths of over five metres and weigh as much as 600 kilograms. Megalania had razor-sharp teeth and claws, perfect for tearing into its prey. These large lizards compensated for their lack of speed by lying in wait to ambush victims, and sought out carrion using their excellent sense of smell.



Super-sized serpent

TITANOBOA ▶ 60-58 MYA

Reaching lengths of up to 15 metres, Titanoboa was one of the largest land animals on Earth following the extinction of the dinosaurs. These colossal serpents lived in the jungles of South America, devouring turtles and crocodiles in single mouthfuls. Titanoboa could hunt on land and in water, slithering or swimming up to its prey undetected, then suddenly leaping up to clamp its powerful jaws over the victim's windpipe.



Terror birds

PHORUSRHACIDAE ▶ 62-2 MYA

These terrifying predators of prehistoric South America were members of the Phorusrhacidae family, known as 'terror birds', and some could reach heights of three metres. Their main weapon was a sharp, hooked beak that could strike victims from above like a pickaxe. The birds' legs were also incredibly strong, and they may have used their feet to kill by repeatedly kicking, or thrown their prey violently to tenderise the meat.

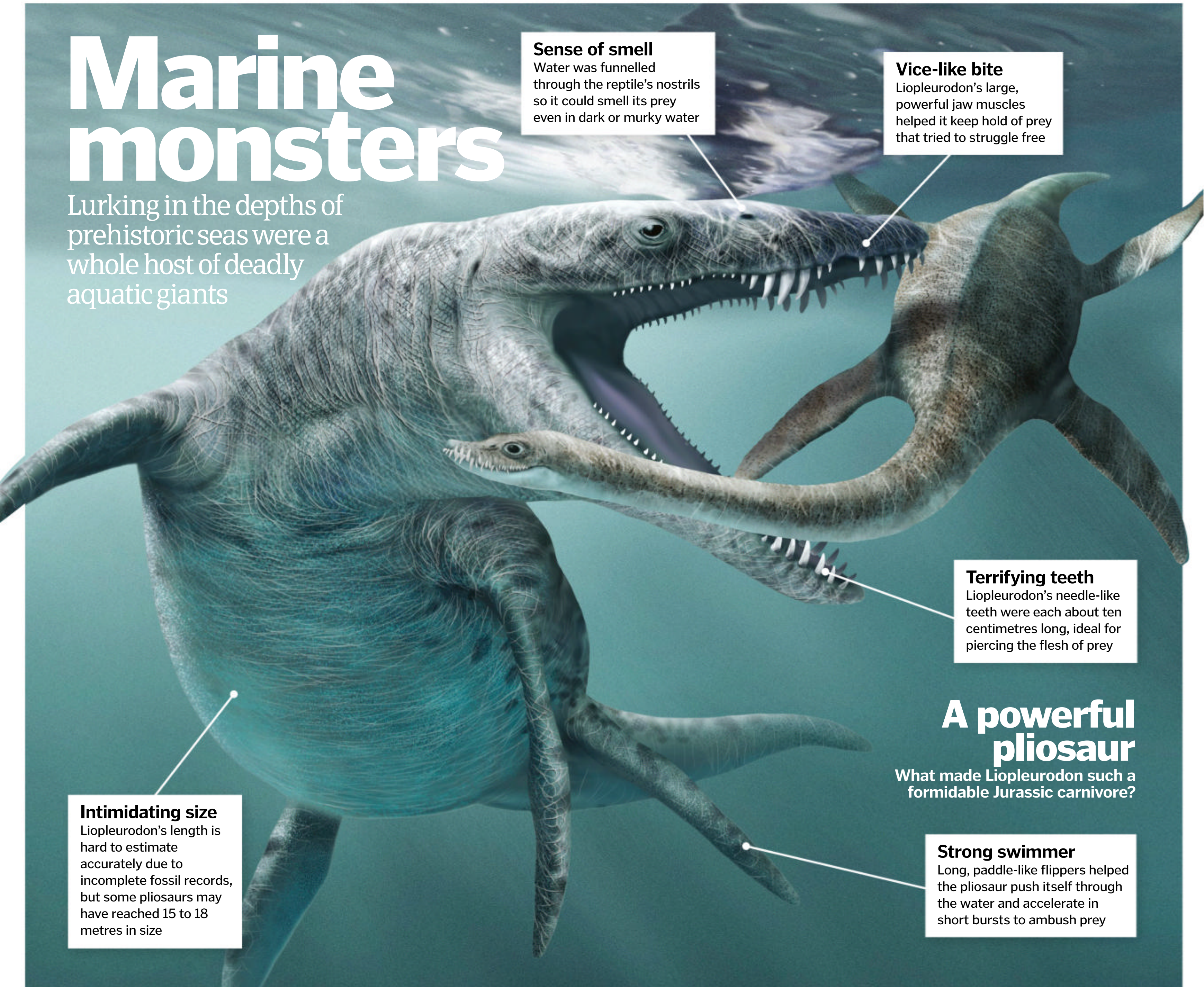
© Alamy; SPL

Marine monsters

Lurking in the depths of prehistoric seas were a whole host of deadly aquatic giants

A powerful pliosaur

What made Liopleurodon such a formidable Jurassic carnivore?



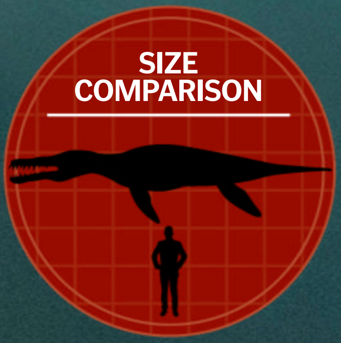
Sense of smell
Water was funnelled through the reptile's nostrils so it could smell its prey even in dark or murky water

Vice-like bite
Liopleurodon's large, powerful jaw muscles helped it keep hold of prey that tried to struggle free

Terrifying teeth
Liopleurodon's needle-like teeth were each about ten centimetres long, ideal for piercing the flesh of prey

Intimidating size
Liopleurodon's length is hard to estimate accurately due to incomplete fossil records, but some pliosaurs may have reached 15 to 18 metres in size

Strong swimmer
Long, paddle-like flippers helped the pliosaur push itself through the water and accelerate in short bursts to ambush prey



Mighty ocean predator

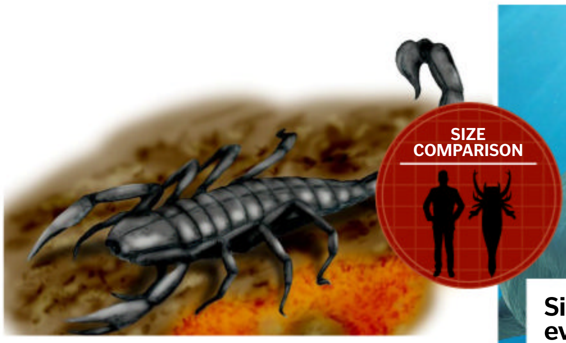
LIOPLEURODON ▶ 160-155 MYA

A fierce killer with a bone-crunching bite

Liopleurodon was among the most powerful predators ever known on Earth, with a bite possibly even stronger than that of the mighty T rex. It belonged to a group of marine reptiles called pliosaurs, which were large with short necks. Liopleurodon's diet primarily consisted of fish and squid, but it would occasionally seek out much larger prey. Huge bite marks that were found in plesiosaur fossils suggest that they were victims of the Liopleurodon's massive jaws, which were packed with sharp teeth. Scientists even estimate that these colossal carnivores would have been strong enough to bite a car in half, if they had existed at the same time!

Liopleurodon may have also had a pale underside to help keep it camouflaged from prey below, allowing it to make ambush attacks despite its enormous size.

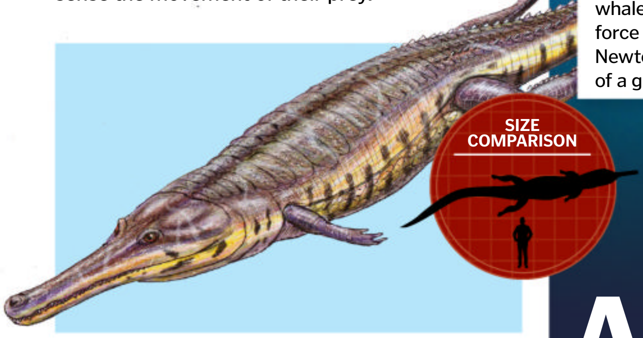
DID YOU KNOW? *Megalodon teeth were once believed to be petrified dragon tongues that had broken off when the dragon died*



Giant sea scorpion

PENTECOPTERUS ▶ 467 MYA

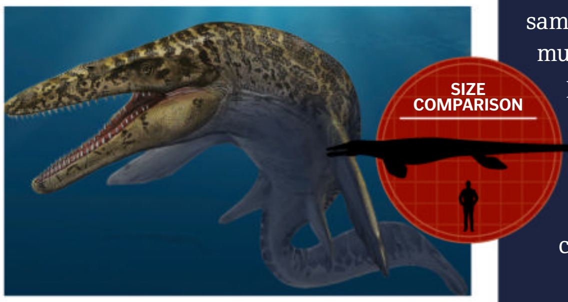
Over 200 million years before the first dinosaurs emerged, this nightmarish Pentecopterus was an important Palaeozoic predator. These arthropods grew to lengths of around 1.8 metres, and used their large limbs to grab prey. Young lived on the seabed while adults mainly resided in shallow waters to avoid larger predators. These super-sized scorpions also had hairs that helped them to sense the movement of their prey.



King-sized croc

MACHIMOSAURUS ▶ 130 MYA

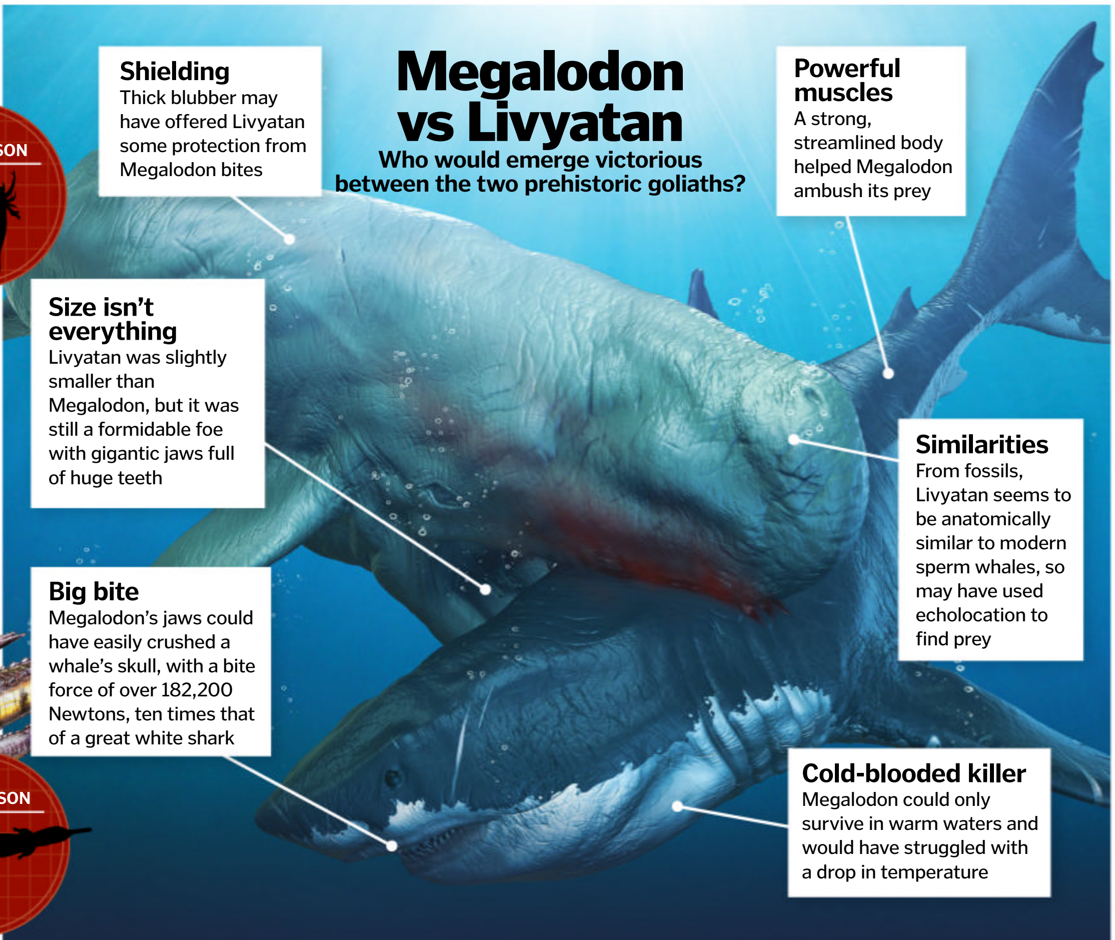
Lurking in Cretaceous seas, Machimosaurus was a colossal crocodile at nearly ten metres long, almost twice the size of its biggest modern relatives. Its teeth were best suited for crushing shells and crunching bones rather than slicing through flesh. Machimosaurus' main tactic was to hide in shallow water and, without warning, clamp its mouth shut on a turtle or fish. Once its prey was caught in the jaws, there would be no escape.



Apex ocean reptile

MOSASAURUS ▶ 80-66 MYA

The massive Mosasaurus was a giant aquatic lizard and dominant predator in Cretaceous-era oceans. Some grew to 15 metres or more, and had long, powerful tails to propel themselves through water. They preyed on reptiles, fish, sharks and shellfish, snapping their tough shells with powerful jaws. As an air-breather, Mosasaurus was unable to dive for prolonged periods, so it was limited to hunting near the ocean surface.



Megalodon vs Livyatan

Who would emerge victorious between the two prehistoric goliaths?

Shielding
Thick blubber may have offered Livyatan some protection from Megalodon bites

Powerful muscles
A strong, streamlined body helped Megalodon ambush its prey

Size isn't everything
Livyatan was slightly smaller than Megalodon, but it was still a formidable foe with gigantic jaws full of huge teeth

Similarities
From fossils, Livyatan seems to be anatomically similar to modern sperm whales, so may have used echolocation to find prey

Big bite
Megalodon's jaws could have easily crushed a whale's skull, with a bite force of over 182,200 Newtons, ten times that of a great white shark

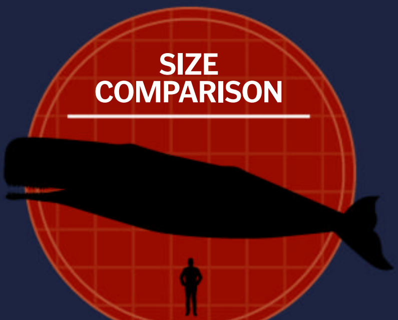
Cold-blooded killer
Megalodon could only survive in warm waters and would have struggled with a drop in temperature

A real-life leviathan

LIVYATAN ▶ 13-12 MYA

A killer sperm whale with one of history's biggest bites

Hebrew for 'leviathan', Livyatan was roughly the same size as a modern sperm whale, but it was a much more formidable hunter. The 50-ton beasts probably competed with Megalodon for food, preying on smaller whales, cetaceans like dolphins, and large fish. Livyatan teeth are possibly the largest of any animal at over 30 centimetres long, and its bite force could rival that of the Megalodon.

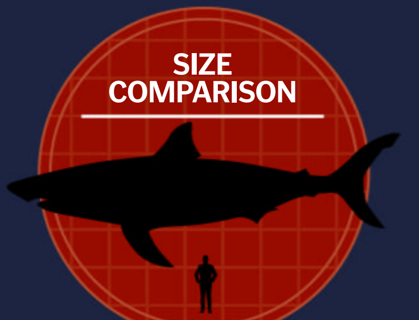


Super-sized shark

MEGALODON ▶ 28-1.6 MYA

Meet the colossal sharks that dwarfed great whites

These gigantic 75-ton sharks were so big that they could hunt whales with ease. Up to 20 metres long and equipped with a mouth full of teeth as large as a human hand, these mega-sharks made short work of dolphins, whales, seals, squid and other sharks. When faced with a turtle shell, they snapped it in two. It is estimated that Megalodon had one of the strongest bite forces of any animal that's ever lived, capable of crushing a small car.



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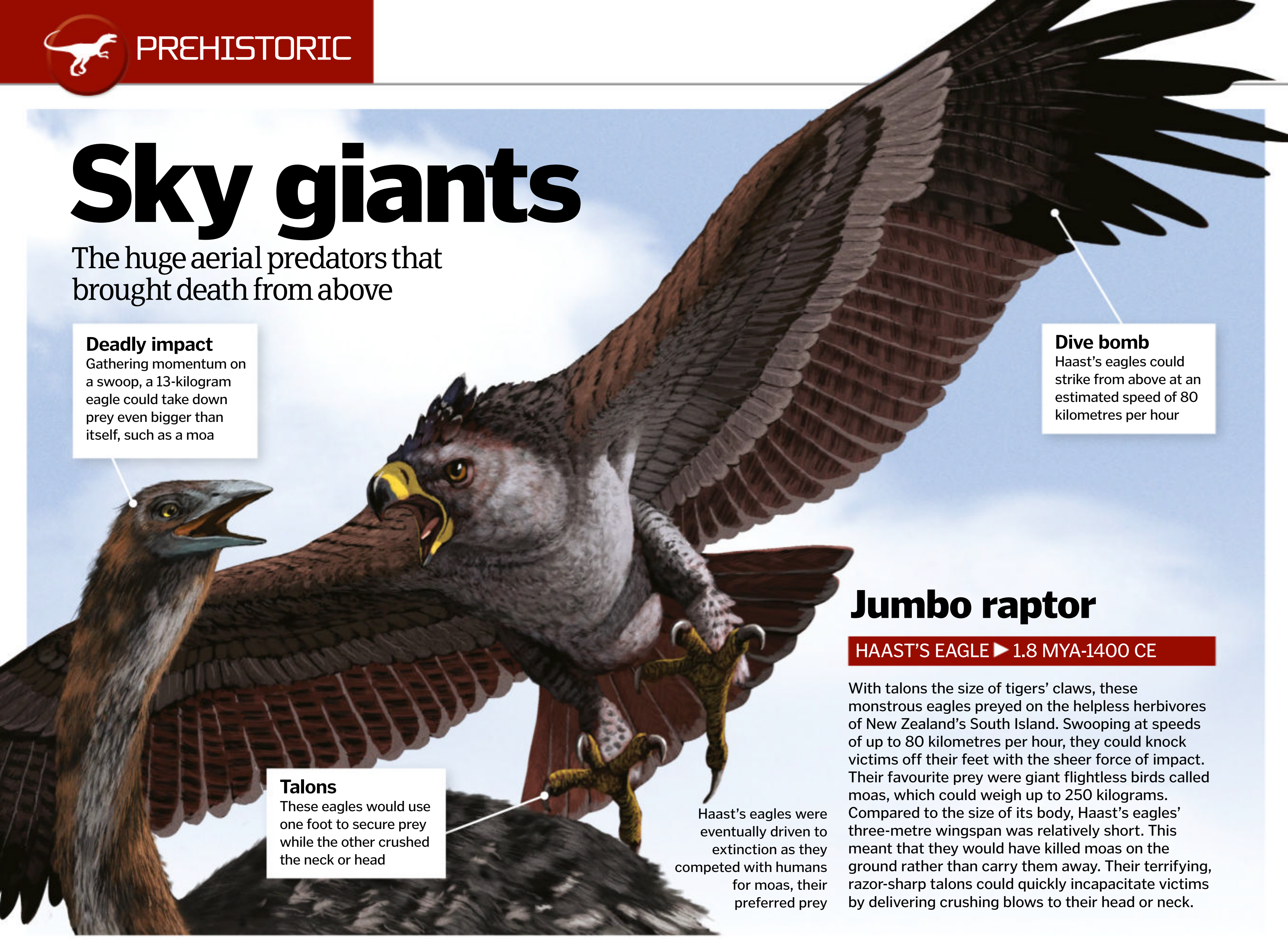
Sky giants

The huge aerial predators that brought death from above



Deadly impact
Gathering momentum on a swoop, a 13-kilogram eagle could take down prey even bigger than itself, such as a moa

Dive bomb
Haast's eagles could strike from above at an estimated speed of 80 kilometres per hour

Talons
These eagles would use one foot to secure prey while the other crushed the neck or head

Haast's eagles were eventually driven to extinction as they competed with humans for moas, their preferred prey

Jumbo raptor

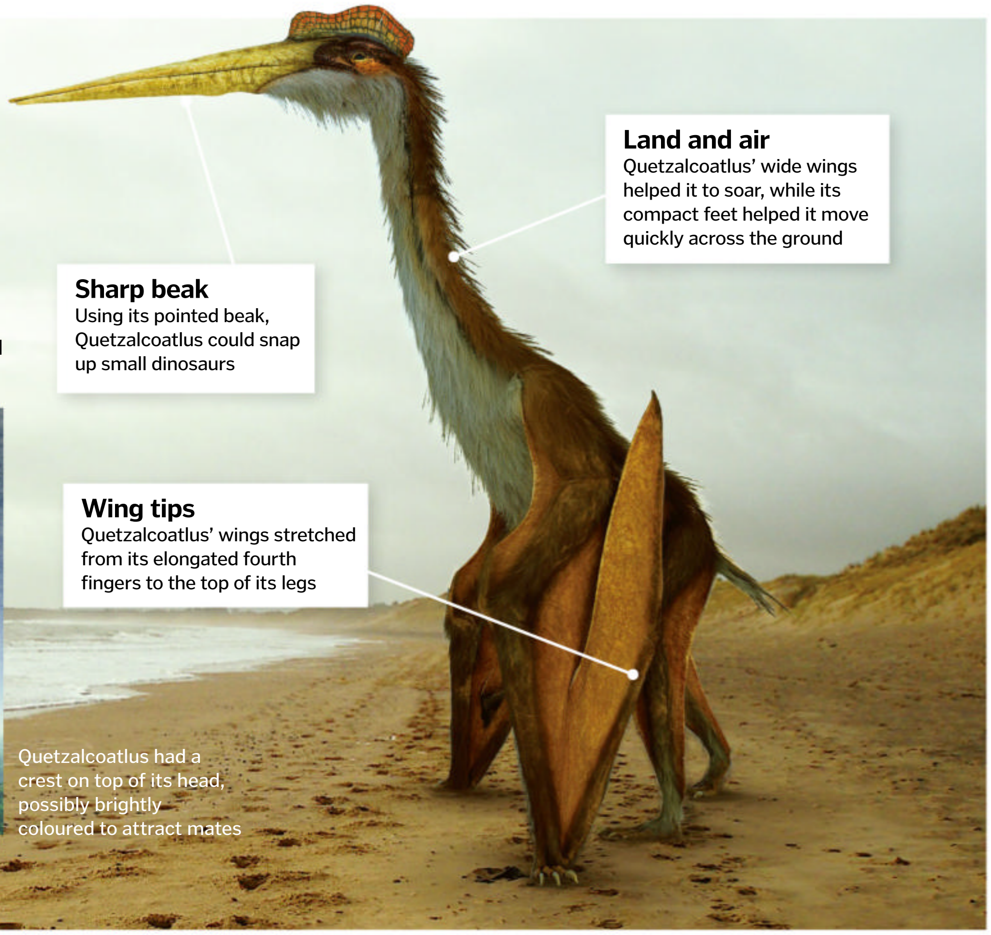
HAAST'S EAGLE ▶ 1.8 MYA-1400 CE

With talons the size of tigers' claws, these monstrous eagles preyed on the helpless herbivores of New Zealand's South Island. Swooping at speeds of up to 80 kilometres per hour, they could knock victims off their feet with the sheer force of impact. Their favourite prey were giant flightless birds called moas, which could weigh up to 250 kilograms. Compared to the size of its body, Haast's eagles' three-metre wingspan was relatively short. This meant that they would have killed moas on the ground rather than carry them away. Their terrifying, razor-sharp talons could quickly incapacitate victims by delivering crushing blows to their head or neck.

Plane-sized pterosaur

QUETZALCOATLUS NORTHROPI ▶ 70-65 MYA

Quetzalcoatlus was the largest-known species of pterosaur, the group of flying reptiles that lived alongside dinosaurs. With a wingspan of ten metres or more, it was roughly the size of a small jet plane. Its toothless beak suggests that it hunted small prey that didn't require chewing, such as baby dinosaurs, and possibly also scavenged for carrion. Quetzalcoatlus is also thought to have roamed on land, because it had small, cushioned feet that were suited to moving over firm terrain. If this is true, it may have hunted like a modern-day stork, snatching small prey up in its beak.



Land and air
Quetzalcoatlus' wide wings helped it to soar, while its compact feet helped it move quickly across the ground

Sharp beak
Using its pointed beak, Quetzalcoatlus could snap up small dinosaurs

Wing tips
Quetzalcoatlus' wings stretched from its elongated fourth fingers to the top of its legs

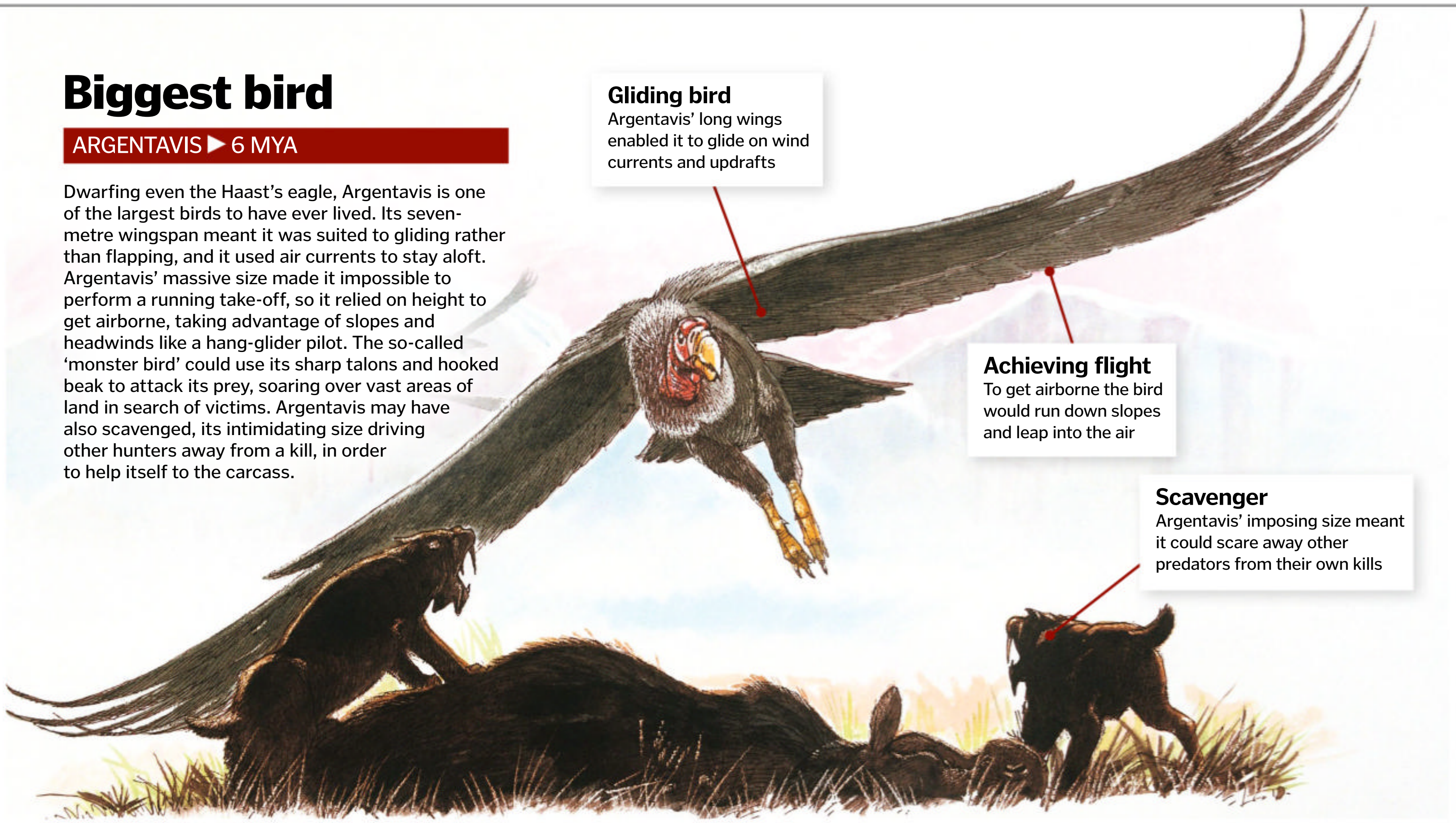
Quetzalcoatlus had a crest on top of its head, possibly brightly coloured to attract mates

DID YOU KNOW? *One of the largest dinosaurs discovered so far is an as-yet-unnamed, 37m-long, 70-ton Titanosaur*

Biggest bird

ARGENTAVIS ▶ 6 MYA

Dwarfing even the Haast's eagle, Argentavis is one of the largest birds to have ever lived. Its seven-metre wingspan meant it was suited to gliding rather than flapping, and it used air currents to stay aloft. Argentavis' massive size made it impossible to perform a running take-off, so it relied on height to get airborne, taking advantage of slopes and headwinds like a hang-glider pilot. The so-called 'monster bird' could use its sharp talons and hooked beak to attack its prey, soaring over vast areas of land in search of victims. Argentavis may have also scavenged, its intimidating size driving other hunters away from a kill, in order to help itself to the carcass.



Gliding bird
Argentavis' long wings enabled it to glide on wind currents and updrafts

Achieving flight
To get airborne the bird would run down slopes and leap into the air

Scavenger
Argentavis' imposing size meant it could scare away other predators from their own kills

Gigantic fly

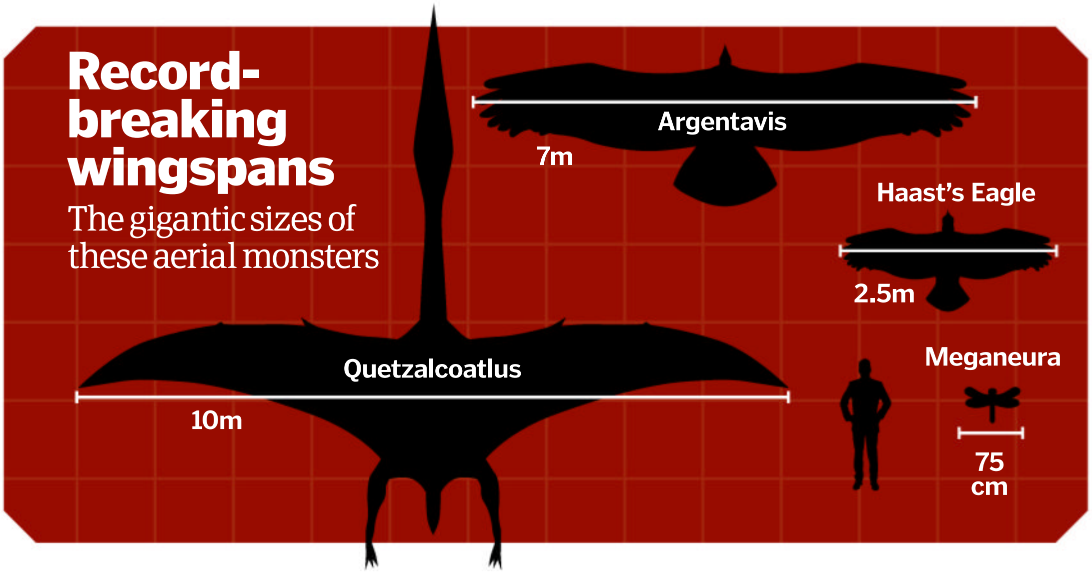
MEGANEURA ▶ 300 MYA

One of the biggest insects to ever exist, the Meganeura was a member of the griffinflies, which are closely related to dragonflies. This prehistoric insect benefited from a higher percentage of oxygen in the atmosphere in the period in which it lived. This allowed it to grow to and maintain its huge size. It used its large eyes to spot prey such as small amphibians and other insects, which it grabbed with its legs while in midair.

The Meganeura's 75-centimetre wingspan was larger than that of a magpie

Record-breaking wingspans

The gigantic sizes of these aerial monsters



Why were prehistoric animals so big?

It had previously been accepted that prehistoric animal size was a result of Cope's Rule. Named after American palaeontologist Edward Drinker Cope, the theory suggested that dinosaur gigantism was down to the notion that animals naturally evolve to be bigger. When mass extinctions occur, new smaller animals replace the larger extinct ones, and the process begins anew. As it has 'only' been 66 million years since the Cretaceous mass extinction, and 12,000 years since the last ice age, animals on Earth are now smaller because they haven't yet had enough time to evolve to reach such large sizes once again.

Another theory suggested that environmental factors, such as higher oxygen levels and warmer temperatures, could have played a significant role in gigantism. Cold-blooded reptiles benefited from the toasty climate as it allowed for efficient digestion, circulation and respiration, as well as an abundance of vegetation to consume.

More recent research and fossil discoveries have cast doubt on both these theories, though. Some creatures seemed to evolve to be smaller rather than larger over time, and many different-sized animals existed at the time. One explanation for why dinosaurs in particular were typically large is because they where physiologically similar to birds. Their bones had air pockets in them, making even large species relatively light, so they wouldn't collapse under the weight of their own bodies.

Not all of the biggest beasts were prehistoric, though. In fact, the heaviest animal ever to exist on planet Earth is still alive today: the blue whale. Marine animals can grow to epic proportions because the buoyancy from water helps to balance the force due to gravity. This supports their considerable masses, and allows for far larger body sizes than on land.

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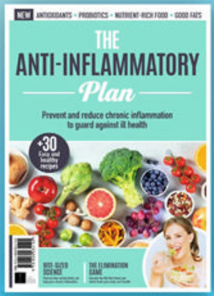
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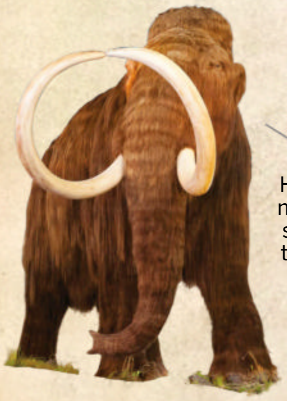
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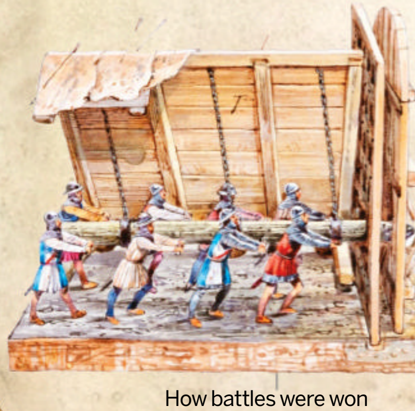
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